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INCINERATION OF BULKY REFUSE WITHOUT PRIOR SHREDDING

NEW YORK UNIVERSITY

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problem of disposing of oversized wastes, the study described here investigated the practical aspects of design and operation of batch-charged furnaces with refractory hearths for incinerating mixed oversized wastes. Special reference was given to combustion and control of air pollution.

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INCINERATION OF BULKY REFUSE WITHOUT PRIOR SHREDDING

by

Elmer R. Kaiser, Daniel Kasner and Charles Zimmer

OBJECTIVE OF PROJECT

The objective of the present project was to investigate the practical aspects of design and operation of batch-charged furnaces with refractory hearths for incinerating mixed oversized wastes, with special reference to the combustion and air pollution. Prior preparation of the refuse, as by shredding, was to be avoided for reasons of simplicity and economy.

INTRODUCTION

Parks, homes and commercial enterprises generate large quantities of refuse, among which are tree branches, logs and stumps, furniture, mattresses, crates, boxes, skids, pallets, truck tires, and demolition lumber. Too large to be burned with regular refuse in conventional incinerators, and wasteful of landfill space, such bulky or oversized combustible waste requires special means for disposal.

Open burning of piles of the material has demonstrated the feasibility of burning for volume reduction to fine ash and associated metallics. However, open burning is being outlawed because of air pollution. Mechanical shredding of large refuse, followed by landfilling or burning in conventional incinerators, requires a large investment.

The design of special furnaces for smokeless burning of oversized wastes, and for control of air pollution to established limits, has been handicapped by a lack of test data and design procedures. It is the hope of the authors that the experience and suggestions presented in this report will aid engineers in the design of successful bulky-waste incinerators.

SUMMARY

Households, commercial establishments, industries and parks generate combustible wastes that are over four feet in length and three inches in diameter, which are usually classified as oversized or bulky waste. Roughly 5 to 10 percent of municipal waste is included in that category. Conventional municipal incinerators are not designed for burning such wastes without loss of capacity.

This report illustrates a type of incinerator which is suitable for burning oversized wastes without smoke and without the necessity for prior sorting or shredding. The furnace is capable of burning logs and stumps of any size that can be charged into it by a tractor. It is also able to burn diverse mixtures of solid wastes to a mineral ash and to metal free of organic matter. The incinerator is roofed and does not need a building.

After delivery by truck, the waste is dumped on a concreted area around the front of the primary furnace. A rubber-tired front-end loader with detachable pusher blade slides 500 to 1000-pound heaps across the apron, under a wide guillotine door, and onto a refractory hearth at ground level. Waste may be charged every 15 minutes or as indicated by the furnace pyrometer. Forced underfire and overfire air complete the combustion. Ample time is afforded for burning heavy logs and stumps. After an 8-hr day of charging, the fire is allowed to burn down overnight and for the furnace to cool slowly. Depending on the amount of residue accumulated, residue is removed daily or less frequently by the same tractor.

A procedure is outlined for designing the configuration of combustion chambers, primary and secondary, and for sizing the air ducts, ports, and blowers. By means of mass and heat balances, the volumes of air and flue gas are determined. Details as to refractories, steelwork, doors, roof and chimney construction are left to the ingenuity and discretion of design engineers and suppliers. The principles and design factors were derived from tests on full-scale furnaces. Several incinerators based on some or all of these principles have been in success-

ful operation for several years.

Every effort has been made to keep the design as simple as possible for construction and operation, consistent with reliability and durability. The instrumentation needed is primarily a draft gage and a pyrometer.

A reliable operator can soon acquire the experience necessary for charging the furnace by tractor and for removing the residue without producing smoke or damaging the refractories.

Although the emission of fly ash is relatively low, air pollution control equipment will be required to meet the strict, new regulations. Either an electrostatic precipitator or a gas scrubber will serve the purpose. The quantity of gas to be cleaned can be calculated by the method given in the report.

DESIGN PROCEDURE AND FACTORS

The designing of an incinerator for bulky refuse offers opportunities for innovation. The limited experience to date has only partially narrowed the choices. Based on tractor charging of unshredded bulky waste, the following design procedure for an installation, 5,000 lb per hour, will present the design factors indicated by the tests and installations observed. Figure 1 illustrates the basic design.

Given: Average charging and burning rate in pounds per hour of mixed bulky refuse.

Average refuse analysis and calorific value.

Charging during one 7 to 10 - hr shift per day.

Overnight burn-out of charge.

Residue removal in morning by front-end loader.

Flue gas scrubber or electrostatic precipitator.

Electric power.

Charging tractor(s) with pusher blade and bucket.

Truck for residue.

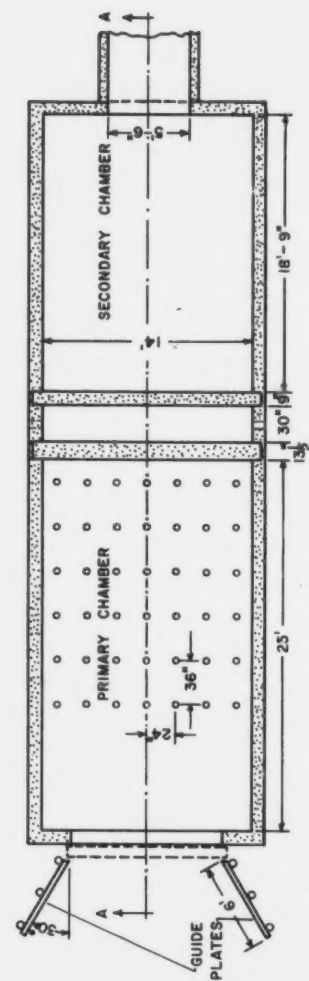
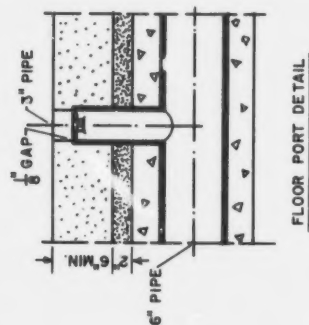
Design Factors. Primary furnace floor area = Avg. charging (burning) rate in pounds per hour $\div$ 15 = square feet.

Primary furnace height = 12 feet minimum to prevent touching refractory arch with demolition lumber or other long objects during charging.

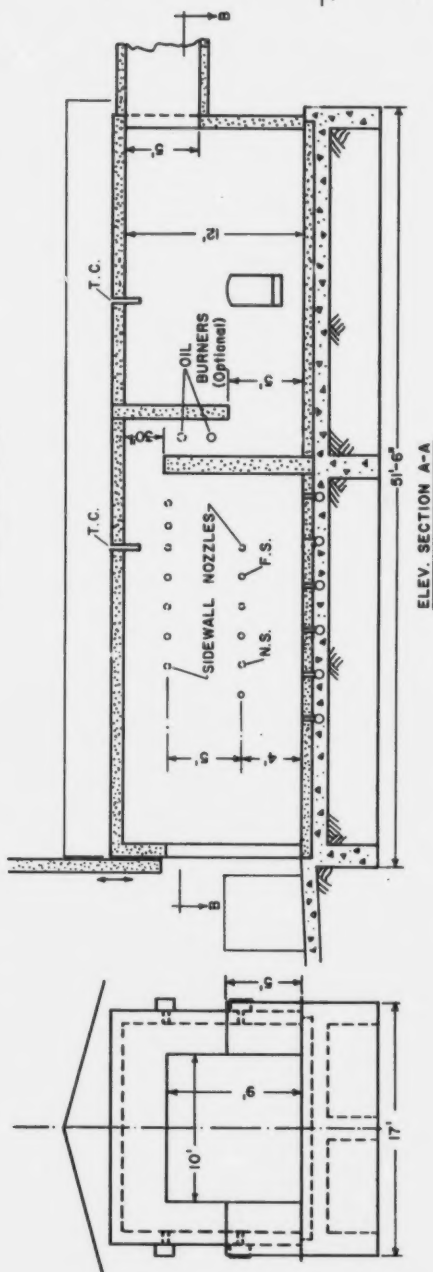
Primary chamber length = 20 ft minimum,
25 ft maximum

Primary chamber width = 8 ft minimum,
16 ft maximum

Charging doorway width = 8 - 10 ft
height = 7 - 9 ft.



PLAN SECTION B-B



ELEV. SECTION A-A

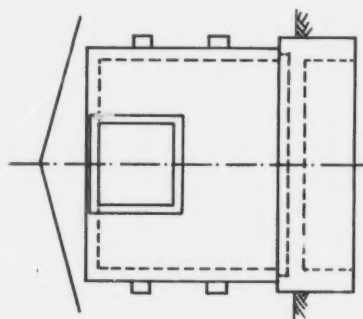


FIGURE 1. BULKY-REFUSE INCINERATOR. CAPACITY 5000 POUNDS PER HOUR.

Smoke out charging door is minimal with least height, but opening must be high enough to permit tractor with operator to enter and remove residue without touching lintel.

Charging Door. Overlaps doorway by 3 to 6 inches at each side and top. Guillotine door preferable to sliding doors.

Secondary chamber volume = $2/3$ primary chamber volume.

Total air supply for 175 % excess over stoichiometric, approximately equal to 1,800 lb dry air + air moisture per million Btu in refuse or 13.6 lb air per lb of 7,500 Btu refuse.

Air Distribution. 13 % through floor ports
 47 % overfire air jets
 40 % infiltration from charging door

Select blower(s) with 25 % extra capacity (cfm) and 15 % extra blower static pressure for control purposes.

Use floor air ports in primary chamber only: 3 in. diameter pipe with 2.75 in. disk. See sketch, Figure 1. Velocity from annulus 6,000 ft/min. = 47 cfm per air port.

Underfloor air manifold: 6-in. pipe buried in concrete. Space air ports 3 ft x 2 ft, such as 2 ft spacing along manifold, with manifolds 3 ft apart, center to center.

Static pressure in underfloor air manifold: 6 inches water gage.

Sidewall Air Jets. Select pipe size from Figure 2 , for air delivery and jet penetration at least to center of furnace. Locate jets to penetrate flame, and to provide oxygen and turbulence in flames which will move upward and toward exit above bridgewall.

Infiltration of Air Around Charging Door. Desirable.

Allow clearances of $3/4$ in. around charging door to prevent binding of ways and to permit air infiltration. Cold air leakage drifts to

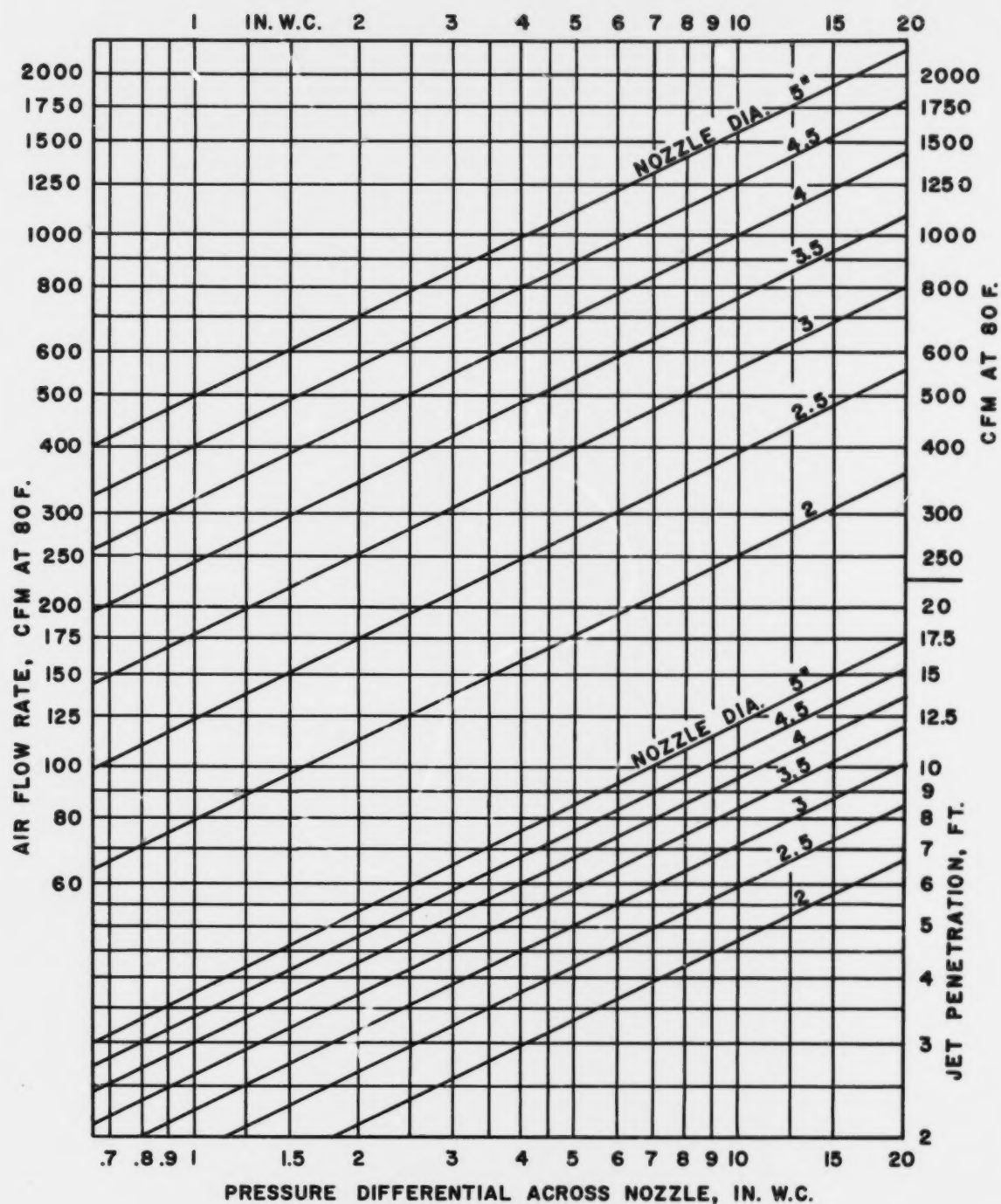


Figure 2. Air Flow and Jet Penetrations

floor and supports combustion at front of furnace.

Bridgewall. Distance between bridgewall and arch is based on 1,800 fpm average gas velocity over bridgewall, usually about 3 ft.

Curtain wall is spaced same distance behind bridgewall as above.
2.5 - 3 ft.

General. Test data for the design are limited. It is necessary to use best estimates and reasonable approximations, as well as safe, conservative designing. Savings in initial cost will prove uneconomical in final cost per ton processed.

Example Design Calculations

Given Bulky waste, 60 to 100 tons per week, averaging 85 tons/week = 175,000 lb. Five-day operating week, 7 hr/day = 35 hr/wk.

Assume: 7,500 Btu/lb for refuse. 7 hr/day for refuse charging, with overnight burndown.

$$\begin{aligned}\text{Design burning rate} &= 175,000/35 \\ &= 5,000 \text{ lb per hr}\end{aligned}$$

<u>Refuse Analysis.</u>	Moisture	15.0	
	Carbon	38.0	
	Hydrogen	5.0	7,500 Btu/lb, higher
	Oxygen	28.0	heating value (HHV),
	Nitrogen	0.4	excluding heat from
	Sulfur	0.2	partial oxidation
	Chlorine	0.4	of metal.
	Metal, glass, ash	<u>13.0</u>	
		100.0	

Outside air at 80 F, 60 % relative humidity.

Heat from oxidation of metal at 10,000 Btu per pound of oxygen absorbed.

Combustion virtually completed in secondary chamber.

Fly ash (75 % ash, 25 % carbon) leaving secondary chamber in gases = 0.5 % of refuse.

Area of primary chamber floor equals $5,000/15 = 333 \text{ sq ft.}$

Use 14 ft x 25 ft = 350 sq ft.

MASS BALANCE FOR PRIMARY CHAMBER

<u>Input</u>			<u>Lb/hr</u>
Bulky refuse			5,000
Moisture	15.0 %	750 lb	
Carbon	38.0	1,900	
Hydrogen	5.0	250	
Oxygen	28.0	1,400	
Nitrogen	0.4	20	
Sulfur	0.2	10	
Chlorine	0.4	20	
Metal, glass, ash	<u>13.0</u>	<u>650</u>	
	100.0 %	5,000 lb	
Dry air at 175 % excess over stoichiometric			67,256
To burn carbon	$2.75 \times 1,900 \times 11.53$	= 60,244	
To burn hydrogen	$2.75 \times (250 - 1,400/7.94)$	$34.34 = 6,894$	
To burn sulfur	$2.75 \times 10 \times 4.29$	= 118	
Air moisture at 60 % R.H. and 80 F			
	$67,256 \times 0.0132$		<u>888</u>
Total			<u>73,144</u>

Air Supply. Total air to primary chamber = $67,256 + 888 = 68,144$ lb/hr, $68,144 / (0.075 \times 60) = 15,143$ cfm at ambient 70 F.

Blower air at 60 % = $15,143 \times 0.60 = 9,086$ cfm

Infiltration air at 40 % = $15,143 \times 0.40 = 6,057$ cfm

Floor ports, use six rows of seven each = 42 ports.

Port: 3 in. pipe with 2.75 in. disk, spacing 3 ft x 2 ft.

Area = $42 \times 0.7854(3.0^2 - 2.75^2) / 144 = 0.329$ sq ft.

Cfm = $6,000 \times 0.329 =$

Air Cfm
1,974

Sidewall Nozzles. Air delivery = $9,086 - 1,974 =$

7,112

Air per 3 in. diameter nozzle with 7 ft penetration, from chart, 550 cfm at 9.6 in. wc pressure.

Number of nozzles = $7,112 / 550 = 12.9$, use 13.

Space nozzles as shown in Figure 1 .

Infiltration Air. Enters mainly through clearances

6,057

around charging door and minor amount through joints of refractories. Average crack width around door is

0.75 in. Total area of crack is $3 \times 10 \times 12 \times 0.75 =$

270 sq in. = 1.9 sq ft. Bottom of door $10 \times 12 \times 1.5 =$

180 sq in. = 1.2 . Assume leakage area of joints =

0.5 sq ft.

3.6 sq ft.

Velocity through cracks and joints = $6,057 / 3.6 =$

1,690 fpm.

Total cfm

15,143

MASS BALANCE FOR PRIMARY CHAMBER

<u>Output</u>	<u>Lb/hr</u>
Dry gas	68,605
CO ₂ 3.667(1,900-42-12-25-16-25-20) = 6,472	
SO ₂ 10 x 2 = 20	
HCl 20 + 0.6 = 20.6	
CO 42 x 28/12 = 98	
H ₂ = 7	
CH ₄ 12 lb carbon + 4 lb hydrogen = 16	
O ₂ By oxygen balance = 10,265	
N ₂ 0.7685(67,256) + 20 = 51,706.4	
Incandescent soot in flames	25
Tar vapor, hydrocarbons 16 lb C + 2 lb H	18
Water vapor	
750 + (250 - 0.6 - 7 - 4 - 2)8.94 + 888	3,751
Fly ash 25 lb carbon, 25 lb ash	50
Residue	695
Carbon = 20 lb	
Metal, glass, ash 650 - 25 = 625	
Oxygen to metal = 50	
Total	73,144
Moisture ratio = $100 \times 3,751 / (3,751 + 68,605) = 5.19 \%$	

HEAT BALANCE OF PRIMARY CHAMBER

Base: 80 F, water as liquid

<u>Input</u>	<u>Btu/hr</u>
Calorific value of refuse, $5,000 \times 7,500$	37,500,000
Heat from oxidation of metal, approx. $10,000 \times 50$	500,000
Heat of vaporization of air moisture $888 \times 1,048.6$	<u>931,157</u>
Total	38,931,157
<u>Output</u>	
Sensible heat in dry gas at 1,580 F $68,605 \times 394$, adjusted	27,128,822
Superheat in water vapor at 1,580 F $3,751 (1,847.3 - 1,096.6)$	2,845,876
Heat of vaporization of moisture at 80 F $3,751 \times 1,048.6$	3,933,299
Sensible heat in soot and fly ash at 1,580 F $(25 + 50)(0.28)(1,580 - 80)$	31,500
Latent and sensible heat in tar vapor $18(100) + 18(0.5)(1,580 - 80)$	15,300
Chemical heat in unburned products	2,546,280
CO $98 \times 4,347 = 426,006$	
H ₂ $7 \times 61,100 = 427,700$	
CH ₄ $16 \times 23,879 = 382,064$	
Tar $18 \times 18,000 = 324,000$	
Carbon $(25+25+20)14,093 = 986,510$	
Sensible heat in residue at 800 F $695 \times 0.20(800 - 80)$	100,080
Heat losses at 5 %	<u>2,330,000</u>
Total	38,931,157

AVERAGE GAS VOLUMES LEAVING PRIMARY CHAMBER AND GAS ANALYSES

Gas	Lb/hr	x Cu ft/lb*	x Factor**	= Acfm***	Wet gas vol. %	Dry gas vol. %
CO ₂	6,472	x 8.548	x 0.0654	= 3,615	5.80	6.31
SO ₂	20	x 5.770	x 0.0654	= 8	0.01	0.01
HCl	21	x 10.38	x 0.0654	= 14	0.02	0.02
CO	98	x 13.506	x 0.0654	= 86	0.14	0.15
H ₂	7	x 187.72	x 0.0654	= 86	0.14	0.15
CH ₄	16	x 23.57	x 0.0654	= 25	0.04	0.04
Tar vapor	18	x 3	x 0.0654	= 4	0.01	0.01
O ₂	10,265	x 11.819	x 0.0654	= 7,935	12.71	13.88
N ₂	<u>51,706</u>	x 13.443	x 0.0654	= <u>45,458</u>	72.85	79.44
	68,623		Dry gas	57,231		
H ₂ O	<u>3,751</u>	x 21.017	x 0.0654	= <u>5,156</u>	8.28	-
	72,374		Total	62,387	100.00	100.00

* At 60 F, 30" Hg.

** Factor at 1,580 F = $(1,580 + 460)/(520 \times 60) = 0.0654$

*** Actual cu ft per minute at 1,580 F

Area of flue or flame port at exit of primary chamber, or free
area above bridgewall = $62,387/1,800 = 35.0$ sq ft minimum.

With furnace width of 14 ft, free space above bridgewall =
 $35.0/14 = 2.5$ ft.

MASS BALANCE OF SECONDARY CHAMBER

<u>Input</u>	<u>Lb/hr</u>
Same as output of primary chamber, except for residue 73,144 - 695	72,449
<u>Output</u>	
Dry gas	68,549
CO ₂ $3.667(1,900 - 7 - 20 - 10) =$ 6,831	
SO ₂ = 20	
HCl = 20.6	
CO $12 \times 28/12 =$ 28	
O ₂ = 9,943	
N ₂ = 51,706.4	
Water vapor $750 + (250 - 0.5)8.94 + 888$	3,868
Fly ash	25
Ash = 18 lb	
Carbon = 7 lb	
Ash settled in secondary chamber	<u>7</u>
Total	72,449

Moisture ratio = $100 \times 3,868 / (68,549 + 3,868) = 5.35 \%$

HEAT BALANCE OF SECONDARY CHAMBER

Base: 80 F, water as liquid

<u>Input</u>	<u>Btu/hr</u>
Sensible, latent and chemical heat of combustion products from primary chamber	
38,931,157 - 2,430,080 - 20(14,093)	36,219,217
<u>Output</u>	
Sensible heat in dry gas at 1,620 F	
68,549 x 408, adjusted	27,988,549
Superheat in water vapor at 1,620 F	
3,868 (1,867.3 - 1,096.6)	2,981,068
Heat of vaporization of water at 80 F	
3,868 x 1,048.6	4,055,985
Sensible heat in fly ash at 1,620 F	
25(0.25)(1,620 - 80)	9,625
Chemical heat in unburned carbon	
7 x 14,093	98,651
Sensible heat in ash deposited in secondary chamber, at 1,200 F, 7(0.22)(1,200 - 80)	1,725
Heat losses at 3 %	<u>1,083,614</u>
Total	36,219,217

AVERAGE GAS VOLUMES LEAVING SECONDARY CHAMBER AND GAS ANALYSES

Gas	Lb/hr	x Cu ft/lb*	x Factor**	= Acfm***	Wet gas vol. %	Dry gas vol. %
CO ₂	6,831	x 8.548	x 0.0667	= 3,893	6.12	6.70
SO ₂	20	x 5.770	x 0.0667	= 8	0.01	0.01
HCl	21	x 10.38	x 0.0667	= 14	0.02	0.02
CO	28	x 13.506	x 0.0667	= 25	0.04	0.04
O ₂	9,943	x 11.819	x 0.0667	= 7,838	12.34	13.49
N ₂	<u>51,706</u>	x 13.443	x 0.0667	= <u>46,339</u>	72.94	79.74
	68,549		Dry gas	58,117		
H ₂ O	<u>3,868</u>	x 21.017	x 0.0667	= <u>5,420</u>	<u>8.53</u>	-
	72,417	Wet gas Total		63,537	100.00	100.00

* At 60 F, 30" Hg.

** Factor at 1,620 F = $(1,620 + 460)/(520 \times 60) = 0.0667$

*** Actual cu ft per minute at 1,620 F

Area of flue or flame port at exit of secondary chamber

$63,537/2,400 = 26.5$ sq ft. Use 5 x 5.5 ft.

Gas Conditioning Chamber

If the flue gas is to be cooled to 600 F by a system of wetted baffles or water sprays prior to entering an electrostatic precipitator, the resultant gas volume is calculated by mass and heat balances.

Similarly, the gases may be cooled by evaporation of water with wetted baffles to remove fly ash prior to entering an induced draft fan at 600. The mass and heat balances are developed simultaneously and successive approximations are used to establish the water rate.

MASS BALANCE OF CONDITIONING CHAMBER

<u>Input</u>	<u>Lb/hr</u>
Dry gas at 1,620 F from secondary chamber	68,549
Water vapor at 1,620 F	3,868
Fly ash	25
Infiltration air at 2 % of dry gas, assume as dry air	1,371
Supply water, including sprays, 67 gpm	<u>33,532</u>
Total	107,345
<u>Output</u>	
Dry gas at 600 F, $68,549 + 1,371$	69,920
Water vapor at 600 F	18,700
Fly ash at 600 F, assume	25
Run-off water at 150 F, 37 gpm*	<u>18,700</u>
Total	107,345

* Run-off may be considerably less, depending on system used;
it may be recirculated.

HEAT BALANCE OF CONDITIONING CHAMBER

Base: 80 F, water as liquid

<u>Input</u>	<u>Btu/hr</u>
Sensible and latent heats from secondary chamber	
36,219,217 - 1,085,000 - 4,189 - 98,651	35,031,377
Sensible heat in supply water, fresh and re-circulated, if 80 F	0
Total	35,031,377
<u>Output</u>	
Sensible heat in dry gas at 600 F	
69,920 x 129	9,019,680
Superheat in water vapor at 600 F	
18,700 (1,334.8 - 1,096.6)	4,454,340
Heat of vaporization of moisture	
18,700 x 1,048.6	19,608,820
Sensible heat in fly ash at 600 F	
25(0.25)(600 - 80)	3,250
Sensible heat in run-off water at 150 F	
18,700 (150 - 80)	1,309,000
Heat losses	636,287
Total	35,031,377

GAS VOLUME LEAVING GAS CONDITIONING CHAMBER

	<u>Acfm</u>	<u>Percent</u>
Dry gas from secondary chamber cooled to 600 F $68,549(600+460)/(1,620+460)$	= 34,920	71.5
Infiltration air, assume dry, at 80 F $1,371(13,601/60)(600+460)/(80+460)$	= 610	1.2
Water vapor at 600 F $18,700 \times 42.86/60$	= <u>13,358</u>	<u>27.3</u>
Total	48,888	100.0

Gas density = $(69,920 + 18,700)/(48,888 \times 60)$
 = 0.0302 lb/cu ft.

Gas Scrubber

The hot exhaust gas from the secondary combustion chamber can be cleaned of most of its particulate matter and the acid gases HCl and SO₂ by a gas scrubber. The scrubber may or may not be preceded by a quench or spray chamber; the overall result is the same. Calculate by hourly mass and heat balances, assuming the dry gas as air, and allow for 2 % infiltration dry air. Assume 90 % of HCl and 10 % of SO₂ dissolved in water.

MASS BALANCE OF SCRUBBER

<u>Input</u>	<u>Lb/hr</u>
Dry gas at 1,620 F from secondary chamber	68,549
Water vapor at 1,620 F	3,868
Fly ash	25
Infiltration air at 2 % of dry gas	1,371
Supply water, excluding recirculation loop, 53 gpm	<u>26,581</u>
Total	100,394
<u>Output</u>	
Dry gas at 169 F, $68,549 + 1,371 - 0.9(21) - 0.1(20)$	69,899
Water vapor at 169 F, $69,899 \times 0.4163$	29,099
Fly ash not collected	7
Net water run-off, 100 times solids collected, 2.7 gpm	1,350
Solids collected in water run-off, 25 - 7 lb	18
Gases in water run-off	<u>21</u>
Total	100,394

HEAT BALANCE OF SCRUBBER

Base: 80 F, water as liquid

<u>Input</u>	<u>Btu/hr</u>
Sensible and latent heat from secondary chamber	
36,219,217-1,085,000-4,189-98,651	35,031,377
Less heat to fresh supply water at 55 F	
26,581 (80 - 55)	- 664,525
Total	34,366,852
<u>Output</u>	
Sensible heat in dry gas at 169 F	
69,899 (40.641 - 19.221)	1,497,237
Enthalpy of water vapor at 169 F	
29,099 (1,133.8 - 48)	31,595,694
Sensible heat in fly ash not collected	
7 (0.22)(169 - 80)	137
Sensible heat in run-off water, and in solids and gases in run-off water	
1,350(169-80)+ 39 (0.25)(169 - 80)	121,018
Heat losses	1,152,766
Total	34,366,852

GAS VOLUMES OF SCRUBBER EXHAUST

Gas	Lb/hr	x	Cf/lb*	x	Factor**	=	Acfm***	Wet gas vol. %	Dry gas vol. %
CO ₂	6,831	x	8.548	x	0.0201	=	1,170	3.88	6.55
SO ₂	18	x	5.770	x	0.0201	=	2	0.01	0.01
HCl	2	x	10.38	x	0.0201	=	0.4	0.00	0.00
CO	28	x	13.506	x	0.0201	=	7.6	0.03	0.04
O ₂	10,261	x	11.819	x	0.0201	=	2,438	8.08	13.65
N ₂	<u>52,759</u>	x	13.443	x	0.0201	=	<u>14,256</u>	47.25	79.75
	69,899				Dry gas		17,874		
H ₂ O	<u>29,099</u>	x	21.017	x	0.0201	=	<u>12,293</u>	<u>40.75</u>	<u>-</u>
	98,998				Total		30,167	100.00	100.00

* At 60 F, 30" Hg.

** Factor at 169 F = $(169 + 460)/(520 \times 60) = 0.0201$

*** At 169 F, 30" Hg

Stack area at 2,000 fpm = $30,167/2,000 = 15.0$ sq ft

Stack diameter, use = 4' - 6" I.D.

Density of scrubber exhaust = $98,998/(30,167 \times 60)$

= 0.0547 lb/cu ft at 30" Hg and 169 F

Dust loading = $(7/69.899)(12.0/6.56) = 0.183$ lb per 1,000 lb of

dry gas corrected to 12 % CO₂ by Orsat.

Dust loading = $(7 \times 700 \times 629 \times 12.0) / (60 \times 17,874 \times 530 \times 6.56)$

= 0.099 grain per Scf of dry gas at 70 F, corrected to
12 % CO₂ by Orsat.

Fluctuations

(25% Increase in Burning Rate)

During average rated operation the flow rates and temperatures will be as calculated. When the door is opened and refuse is charged, the sidewall forced air is shut off, but the infiltration air enters through the doorway to the extent of the available draft. The gas flow over the bridgewall remains roughly the same.

Soon after refuse is charged, the door is closed, and the sidewall air is restored, the burning rate will increase to a peak exceeding the average by 25 %. The furnace gas temperature will exceed the average previously calculated. The following mass and heat balances explore that condition and show a 300 F rise above the average. The condition does not last more than a few minutes, after which a steady decline ensues.

The hotter gas calls for an increase in tempering sprays and the evaporative loss in the scrubber is increased. Automatic water control maintains the desired final gas temperatures at the induced-draft fan.

MASS BALANCE FOR PRIMARY CHAMBER
At 25 % Increase in Burning Rate
With Same Air Supply

<u>Input</u>			<u>Lb/hr</u>
Bulky refuse	5,000 x 1.25		6,250
Moisture	15.0 %	937.5 lb	
Carbon	38.0	2,375	
Hydrogen	5.0	312.5	
Oxygen	28.0	1,750	
Nitrogen	0.4	25	
Sulfur	0.2	12.5	
Chlorine	0.4	25	
Metal, glass,			
ash	<u>13.0</u>	<u>812.5</u>	
	100.0 %	6,250.0 lb	
Dry air			67,256
Air moisture			<u>888</u>
		Total	74,394

Continued MASS BALANCE FOR PRIMARY CHAMBER
At 25 % Increase in Burning Rate

<u>Output</u>	<u>Lb/hr</u>
Dry gas	69,128
CO ₂ 3.667(2,375-53-15-31-20-31-20) = 8,085	
SO ₂ 12.5 x 2 = 25	
HCl 25 + 0.7 = 25.7	
CO 53 x 28/12 = 123	
H ₂ = 9	
CH ₄ 15 lb carbon + 5 lb hydrogen = 20	
O ₂ By Oxygen balance = 9,129	
N ₂ 0.7685(67,256) + 25 = 51,711.3	
Incandescent soot in flames	31
Tar vapor 20 C + 3 H	23
Water vapor	
937.5 + (312.5 - 0.7 - 9 - 5 - 3)8.94 + 888	4,461
Fly ash 31 C + 25 ash	56
Residue	695
Carbon = 20 lb	
Metal, glass, ash 650 - 25 = 625	
Oxygen to metal = 50	
Total	74,394
Moisture ratio: $100 \times 4,461 / (4,461 + 69,128) = 6.07 \%$	

HEAT BALANCE OF PRIMARY CHAMBER

Base: 80 F, water as liquid

At 25 % Increase in Burning Rate with Same Air Supply

<u>Input</u>	<u>Btu/hr</u>
Calorific value of refuse, $6,250 \times 7,500$	46,875,000
Heat from oxidation of metal, $10,000 \times 50$	500,000
Heat of vaporization of air moisture, $888 \times 1,048.6$	<u>931,157</u>
Total	48,306,157
<u>Output</u>	
Sensible heat in dry gas at 1,860 F $69,128 \times 477$, adjusted	32,971,522
Superheat in water vapor at 1,860 F $4,461(2,008 - 1,096.6)$	4,065,735
Heat of vaporization of moisture at 80 F $4,461 \times 1,048.6$	4,677,805
Sensible heat in soot and fly ash at 1,860 F $(31 + 56)(0.30)(1,860 - 80)$	46,458
Latent and sensible heat in tar vapor $23(100) + 23(0.5)(1,860 - 80)$	22,770
Chemical heat in unburned products	3,041,787
CO $123 \times 4,347 =$	534,681
H ₂ $9 \times 61,100 =$	549,900
CH ₄ $20 \times 23,879 =$	477,580
Tar $18 \times 18,000 =$	324,000
Carbon $(31+31+20)14,093 =$	1,155,626
Sensible heat in residue at 800 F $695 \times 0.20 (800 - 80)$	100,080
Heat losses at 7%	<u>3,380,000</u>
Total	48,306,157

BACKGROUND

Urban communities are facing the problem of disposal of dead trees, old timbers, demolition lumber, discarded furniture and mattresses, automobile and truck tires, advertising signs and other large domestic and industrial combustible wastes.

This class of refuse is designated "bulky waste" or "oversized bulky waste" (OBW). Because of its bulk it cannot be collected by the conventional packer trucks.

Because of size it is not practical to dispose of it in conventional municipal incinerators. Often the size is such as to require too much manual attention for charging into the normal incinerators, or it burns too slowly, or it will damage the grates or tangle the normal residue removal systems of such incinerators.

At present, such refuse is buried in landfills or burned in the open. Nearby land is becoming scarce and haulage costs to more distant areas are rising. The landfill areas are often limited and hence best reserved for incinerator residue. Open burning is being prohibited because of the resultant air pollution. The mechanical shredding of bulky waste to sizes that can be charged to existing incinerators is costly, especially when shredding is preceded by the manual removal of steel frames, upholstery springs, and wire from couches, beds, mattresses, metal chairs, and the like. The steel and iron parts of mixed furniture may constitute 10 to 15 percent of the total charge, while pieces of steel frames often ranged up to 6 feet in length. Steel sheets from tables and signs are often 12 to 18 sq ft in area. Coils of stout wire are found in beds of tires.

Composition of Bulky Refuse

Baffa and Bertilucci^{1*} have reported on the variety and quantities of oversized waste in Suffolk County, Long Island, New York (1 million population) and in New York City (8 million population).

They included as bulky waste materials the items listed in Table 1.

Based on 1,890 loads dumped at four principal disposal facilities by public and private carters, Table 2 lists the range.

The unit weights of various bulky materials determined by loading on a test truck are given in Table 3.

Wide variations in the quantities of material delivered to a disposal site must be expected. For example, trees and branches increase after storms. The quantities of these deliveries are given in Table 4.

Baffa and Bertilucci found what others have observed before and since that undersized materials represent about one half of the bulky waste deliveries. In the pickup of oversized materials it is convenient in a clean-up to load smaller items, such as would be quite acceptable in regular incinerators. Conversely, some furniture items are bulky, while others, such as telephone stands and dining room chairs would break up readily before reaching an incinerator hopper, or in any event would burn completely during 30 minutes in the furnace.

The City of New Rochelle, N. Y. (pop. 76,000) recorded bulky waste under 6-inch logs 15.66 tons a day in 1960-61, with 37.5 tons a day during peak periods. The average was thus about 0.5 lb per capita-day.

* References are given at the end of the report.

TABLE 1

BULKY WASTE MATERIALS

Construction lumber	Railroad ties	Trees, brush, stumps
Rubber tires	Baby carriages	Furniture
Asphalt	Bed springs	Pallets
Automobile parts	Bundles of hay	Christmas trees
Stoves	Wheelbarrows	Crates
Sewing machines	Boilers	Washing machines
Large loads of glass and metallic items	Refrigerators	Driftwood

TABLE 2

WEIGHT DISTRIBUTION OF OVERSIZED WASTE (NEW YORK CITY)

	<u>Weight percent</u>
Trees, stumps, brush	1.3 to 9.6
Furniture and fixtures	1.2 to 40.0
Lumber and remodeling waste	6.3 to 36.0
Cardboard and paper	1.0 to 4.1
Rubbish and other	15.8 to 40.8
Non-burnable	18.7 to 38.8

TABLE 3

UNIT WEIGHTS OF SPECIFIC MATERIALS (NEW YORK CITY)

	<u>Pounds per cubic yard</u>
Trees, stumps and brush	230
Furniture and fixtures	130
Lumber and remodeling waste	355
Cardboard and paper	100
Mixed rubbish	550 - 564
Non-burnable bulk material	175 - 177
Bulk, burnable	131
Driftwood	356
Rubbish and dirt	836

TABLE 4

OVERSIZED BURNABLE DELIVERIES, NEW YORK CITY, IN PERCENT OF AVERAGE

	<u>Construction and Demolition Waste</u>	<u>Residential and Junk</u>	<u>Charitable and Institutional</u>	<u>Commercial and Industrial</u>
Maximum day	350	225	300	250
Maximum 8-hr shift	750	250	300	150
Maximum week	185	160	130	120
Maximum month	140	140	120	115

Analysis of Bulky Refuse

The refuse fired in any charge will usually be a mixture, but will vary from logs of high moisture content and low Btu value to tires of negligible moisture but high calorific value. Furniture, demolition lumber, crates, boxes and pallets are intermediate, but are usually quite dry and of 8,500 Btu per lb of dry combustible.

The moisture content will vary with exposure of the refuse to rain. The proximate and ultimate chemical analyses and higher heating values (HHV) which follow as Table 5 and 6 will represent the condition likely to be encountered in the absence of rain. The analyses can, of course, be adjusted for other moisture contents.

In the presence of heat alone the moisture and volatile matter are distilled. The volatile matter is highly combustible and will produce smoke if insufficient air is present for complete combustion. The fixed carbon represents the charcoal that is burned in the solid. "Ash" includes the inherent ash plus extraneous dirt and paint minerals. Metals are excluded except for the wire in the tire beads.

The complete or ultimate analyses of the same refuse components (Table 6) are necessary to calculate the air requirement and the amount of moisture produced.

TABLE 5
PROXIMATE ANALYSES OF BULKY-REFUSE COMPONENTS, IN PERCENT,
AS FIRED*

	<u>Moisture percent</u>	<u>Volatile Matter percent</u>	<u>Fixed Carbon, percent</u>	<u>Ash**, percent</u>	<u>Btu/lb</u>
Green logs	50.00	42.25	7.25	0.50	4,205
Rotten timbers	26.80	55.01	16.13	2.06	6,368
Demolition soft- wood	7.70	77.62	13.93	0.75	7,916
Waste hardwood	12.00	75.05	12.41	0.54	7,301
Furniture wood	6.00	80.92	11.74	1.34	7,813
Upholstery	6.90	75.96	14.52	2.62	7,479
Cardboard, Corrugated	5.20	77.47	12.27	5.06	7,043
Tires	1.02	64.92	27.51	6.55	13,906

** Metals and glass not included except for tire bead wire.

* By ASTM Methods for Coal and Coke.

TABLE 6
ULTIMATE ANALYSES OF BULKY-REFUSE COMPONENTS, IN PERCENT, AS FIRED

	<u>Mois- ture</u>	<u>Car- bon</u>	<u>Hydro- gen</u>	<u>Oxy- gen</u>	<u>Nitro- gen</u>	<u>Sulfur</u>	<u>Ash*</u>
Green logs	50.00	25.06	3.20	21.13	0.07	0.04	0.50
Rotten timbers	26.80	38.25	4.05	28.58	0.17	0.09	2.06
Demol. softwood	7.70	47.04	5.70	38.63	0.12	0.06	0.75
Waste hardwood	12.00	43.48	5.37	38.42	0.13	0.05	0.55
Furniture wood	6.00	46.64	5.70	40.11	0.14	0.07	1.34
Upholstery	6.90	43.85	5.63	40.57	0.24	0.19	2.62
Cardboard	5.20	41.46	5.42	42.57	0.09	0.20	5.06
Tires	1.02	78.18	6.77	5.86	0.12	1.50	6.55

* Metals and glass not included except for tire bead wire.

Air Required for Combustion

On the basis of the preceding analyses, the theoretical air for combustion is as follows:

	<u>Theoretical Air, lb/lb refuse</u>
Green logs	3.08
Rotten timbers	4.48
Demolition softwood	5.73
Waste hardwood	5.35
Furniture wood	5.62
Upholstery	5.26
Cardboard	4.83
Tires	11.15

Aluminum, iron and steel parts will be partially oxidized in the fire, which requires oxygen from the air supplied. Steel sheet, wire, nails and screws in particular acquire the black oxide coating and gain weight by the amount of oxygen absorbed. As an estimate, the metal may be assumed to be oxidized about 15 percent to Fe_3O_4 with a weight gain of 6 percent. As air is 23.15 percent oxygen by weight and 76.85 percent nitrogen plus argon, the air required for this degree of oxidation is 26 percent of the weight of iron and steel present.

If the metal content of the bulky refuse is 10 percent, the theoretical air per lb of refuse is increased 2.6 percent.

The actual air supplied to the total refuse must exceed the theoretical by about 25 percent at all times for smoke control and by 150 percent or more for temperature control at 1,800 F.

Smoke-Producing Propensities

Deciduous logs and unpainted hardwood produce little smoke under the usual combustion conditions, but conifers and painted wood will produce smoke when heated rapidly after charging. The release of hydrocarbon vapors is rapid, and they do not burn promptly when air and turbulence are limited in the zone immediate to the sources of the vapors.

Rubber, plastics, linoleum and asphalt roofing are particularly rich in volatile matter, which evolves rapidly on heating. The vapors crack into soot and lighter hydrocarbons. Unless mixed rapidly with air and burned completely, the soot is visible as black smoke. The proportion of such materials must be small in the charges to avoid smoke from the primary chamber.

To consume smoke, ample oxygen and turbulence are required, allowing at least 25 percent excess air and maintaining 1,500 F in the gases for smoke burnout. For example, at 150 percent excess air for complete combustion and temperature control, a 10 lb tire requires 279 lb of air, or an air volume at 70 F of 3,720 cu ft. The resultant volume of flue gas at 1,800 F is 15,850 cu ft.

INCINERATION OF BULKY REFUSE

Numerous special incinerators to burn oversized wastes and to fire-clean metals have been custom built during the last 20 years. Among the latter group are furnaces to burn automobile bodies at rates of one to 50 per hour ², furnaces to burn insulation off copper wire ³ and furnaces to burn brake bands off brake shoes ⁴.

The objective of such incinerators is to use fire to convert unwanted organic matter by combustion to carbon dioxide and water vapor, to recover metals for recycling, and to produce an ash residue of minimum volume which is also suitable fill material. In an economic sense fire is a lower-cost process for the destruction of waste and salvage of metal than mechanical or manual disassembly and cleaning.

A basic principle of the bulky-waste incinerators discussed in this report is the charging of a variety of waste sizes without the necessity for shredding, sorting or manual handling. The size of objects charged, such as logs, is limited only by the size of chamber and the ability to move the weight. Mechanical grates are not necessary; the waste is supported on a refractory hearth. Heavy logs and light branches can be burned in the same furnace, regardless of the time necessary. Residue is allowed to accumulate and burn out over night. Removal is by front-end loader with direct transfer to a truck or to a storage pile, with water spraying for cooling any incandescent residue.

Prior Developments by Others

The City of Detroit, Michigan has installed two special refractory furnaces for burning brush and diseased elm trees. The units were designed by Theodore Winkler and described by Clyde L. Palmer ⁵, Morton Sterling ⁶ and others ⁷. The installations are at different locations, and are each complete with main chambers, spray baffles and 6 x 150 ft natural-draft chimneys.

The main chamber is 45 x 12 1/4 x 10 ft high and was charged by tractor with pusher blade. Combustion up to 2,000 F was regulated by forced air supplied through ports in the refractory floor, and through nozzles in the side walls and arch. At the rear of the main chamber a large side door enabled logs to be charged and given ample time to be consumed. The logs were said to decrease in diameter at the rate of about 3 inches per hr. A 99.9 percent reduction of refuse volume was attained.

The ash accumulated on the floor and was removed after about 24 hr (3 days) operation. A scoop was attached to the tractor blade and pushed along the floor of the furnace after an overnight or weekend shutdown, during which the refuse burned out and the setting cooled. The scoop load was wetted under a spray before discharging to a pile or truck.

Fly ash was largely trapped by a spray-and-baffle passage between the furnace and stack. The gases were also cooled to 400 to 700 F by the evaporation of part of the spray water.

The Parks Department of the City of Baltimore, Maryland, had also purchased a log burner of steel construction with refractory lining. The green logs, 9,000 lb, were loaded on a movable rack

which was moved into the furnace in the morning. Natural gas burners ignited the logs and helped to bring up the furnace temperature. Natural-draft air from below and air forced through side wall jets were supplied to sustain combustion. Fly ash was trapped by inertia, as the gases flowed in a curved path around a baffle before venting to a 40 in. x 40 ft stack.

Conical metal (tepee) burners and pit-type burners have also been used for bulky waste, but they have not been as adaptable to temperature control as the refractory furnaces, nor as readily fitted with high efficiency pollution control devices.

TEST FURNACE

Design and Construction

Based on the design requested by the project, Morse Boulger, Inc., New York, N. Y., built the test incinerator shown in Figures 3 and 4 at the Jersey City Incinerator, New Jersey⁸. Figure 3 shows the plate steel exterior of the west side wall, one of the two charging doors at the front, and the breeching with damper at the rear. The latter discharged the combustion gases into a large dust-settling chamber of the main plant. The blower and ductwork supplied air to two ports in the furnace floor and to twelve 3-inch sidewall ports, as well as to four 3-inch air ports in the arch.

The furnace side panels were factory-built in sections. The sections were bolted to each other at the sides and were anchored to a concrete foundation. The suspended firebrick arch was hung from beams whose ends were supported on the side walls. A corrugated aluminum roof provided weather protection.

Figure 4 shows the east side wall and one of the two charging doors. The blower supplied air to two air ports in the furnace floor, and to nine 3-inch air nozzles in the side wall, as well as to four 3-inch air ports in the arch.

In front of the incinerator was an area where bulky trash was dropped on the ground from trucks, public and private.

Figure 5 is an elevation view along the incinerator centerline. The 20 x 10 x 12 ft high refractory chamber had a castable refractory floor at ground level, a 13½ inch thick castable bridgewall, and a rear downpass. The side walls were 6 inches of castable refractory on 1 inch mineral-wool insulation, all anchored to the steel casing with stainless steel rods. The hearth was 6 inches of castable





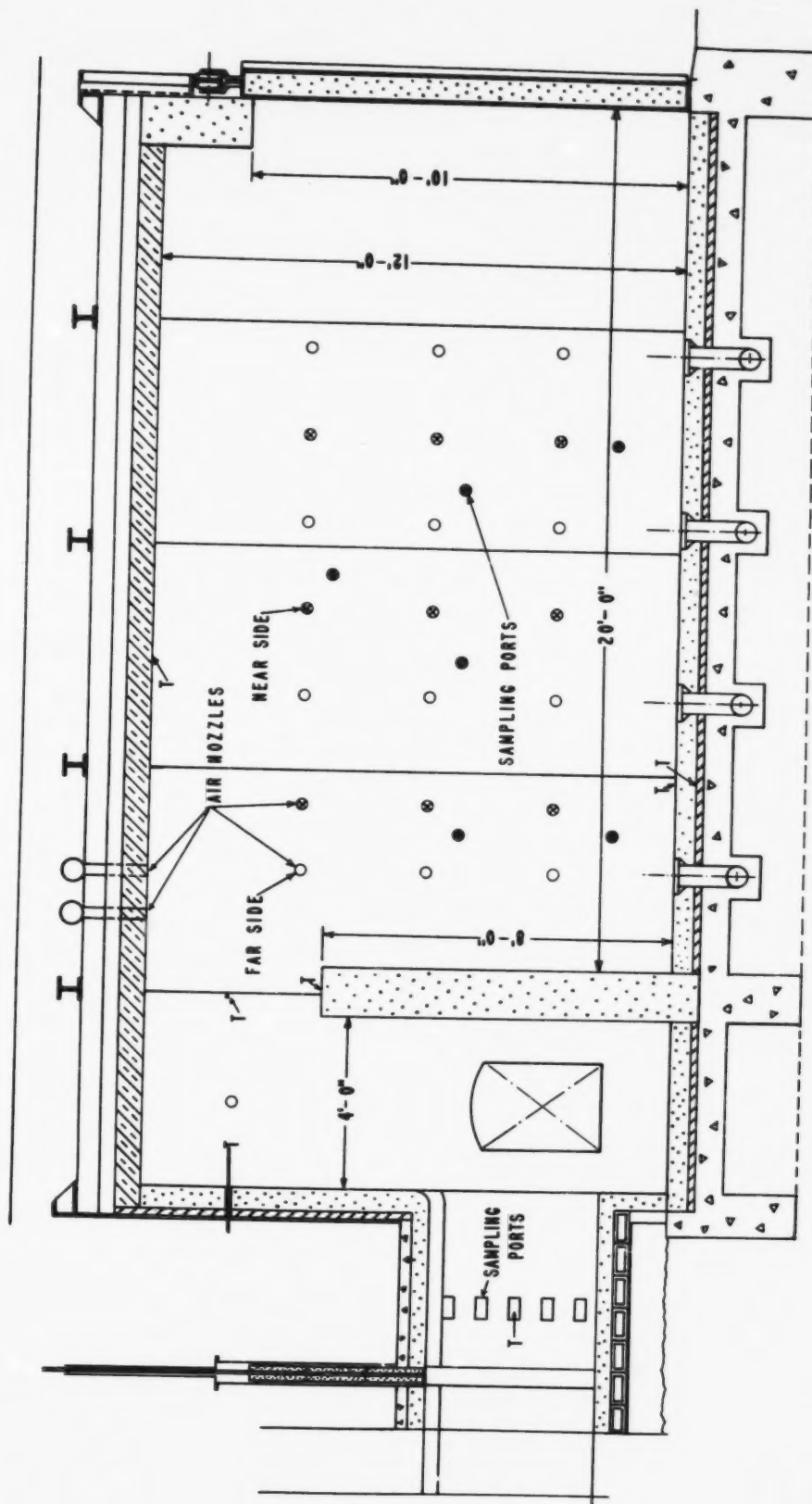


Figure 5. Cross Section in Elevation -- Test Furnace at Jersey City, N. J.

refractory on 2 inches of insulation over concrete. The flat arch was suspended construction of inter-locking, fired, refractory bricks, 7 inches thick.

The hearth area was 200 sq ft. The furnace volume above the hearth was 2,380 cu ft, and 2,905 cu ft before the breeching.

Thermocouples were located at positions marked "T". The gases left the downpass chamber via the 46 x 36-inch wide breeching with sprung arch and cross-sectional area of 11.19 sq ft. The breeching had a counterweighted hanging damper for regulating the draft and for closing when the furnace was not in use. The flue gas discharged into the dry settling chamber of the main incinerator plant and as vented to the atmosphere with the other flue gases via a natural-draft chimney. The research project was, therefore, limited to the performance to the end of the breeching.

The refuse was charged through the two front doors, which were refractory lined and hung from rollers. The doors were operated manually, but could have been designed to be power driven by a chain drive from a motor speed reducer. Access to the downpass chamber and hence the breeching was by a side door.

Two plate-and-pipe barricades were erected to guide refuse into the doorway when pushed by tractor.

The furnace had been in almost daily use for 16 months without refractory maintenance.

Air Supply

Air for combustion was supplied by both natural and forced draft. A slight draft was maintained in the furnace, which caused air to be

induced through the clearances around the main doors. The clearance area totaled 3.3 sq ft. The flow of air through the clearance was about 300 cfm (4,500 lb/hr) when the chamber floor draft was 0.02 inch water column (wc). More air could be admitted by leaving the main doors slightly ajar, but the draft from the main plant settling chamber was limited.

The forced-air system, which was purposely extensive for test purposes, can be described from Figure 5. The two 5,000 cfm blowers which were shown in the previous figures were each provided with air-measuring orifices on inlet ducts. The air was distributed by the manifolds shown in Figures 3 and 4 to air ports shown in Figure 5.

The four air ports in the floor had flush covers designed to discharge air yet prevent ash and small hardware from falling into the 6-inch supply ducts. Each duct had a calibrated control valve with pressure tap connected to manometers for flow measurement. The 21 side wall air nozzles each had calibrated air valves like the floor air valves, which could be regulated from the outside at any time. Note that the side wall nozzles were staggered from opposite walls. Two 6-inch pipe manifolds each with four 3-inch pipe nozzles in the arch provided overfire air upstream of the bridgewall. Each manifold had a separate calibrated air valve. The two rows of nozzles were staggered for maximum mixing of air with the furnace exit gas.

The nozzle diameters were not adjustable, but inserts could be added readily if advisable to reduce the nozzle diameters (areas) and hence to increase the jet velocities.

Hanging Damper

The design of hanging damper in the breeching may be of interest to the reader, as such devices frequently have short lives, especially

when used in the part-open position. As shown in Figure 6, the damper had air-cooled stainless steel hangers to support a 3-section castable refractory panel.

The stainless steel anchors were 5/16-inch rods, each 3 inches long, welded at a 45-degree angle to 3/8-inch, schedule 40 stainless steel pipes. The cooling of the pipes, and hence the maintenance of their strength and life, was accomplished by the flow of outside air down the pipes by the draft in the breeching. The hanger pipes extend upward enough to permit the upper portions of the pipes to be guided in fixed sleeves of 1 1/4-in. iron pipe.

The hanger pipes were anchored in the mold so as to remain parallel. Before the blocks were cast around the hangers, the latter were coated with tar. The tar was expected to melt and/or oxidize away so as to permit the refractory and pipe to expand and contract freely in the heat without stress. It was expected that the refractory would crack in time, but even if it should crack along the pipes, the inclined rods would hold the pieces in place.

The pipes were socketed by collars into the ends of a cross channel, the center of which was supported by the wire rope looped through the pulley. Hence, the counterweight had only half the weight of the damper.

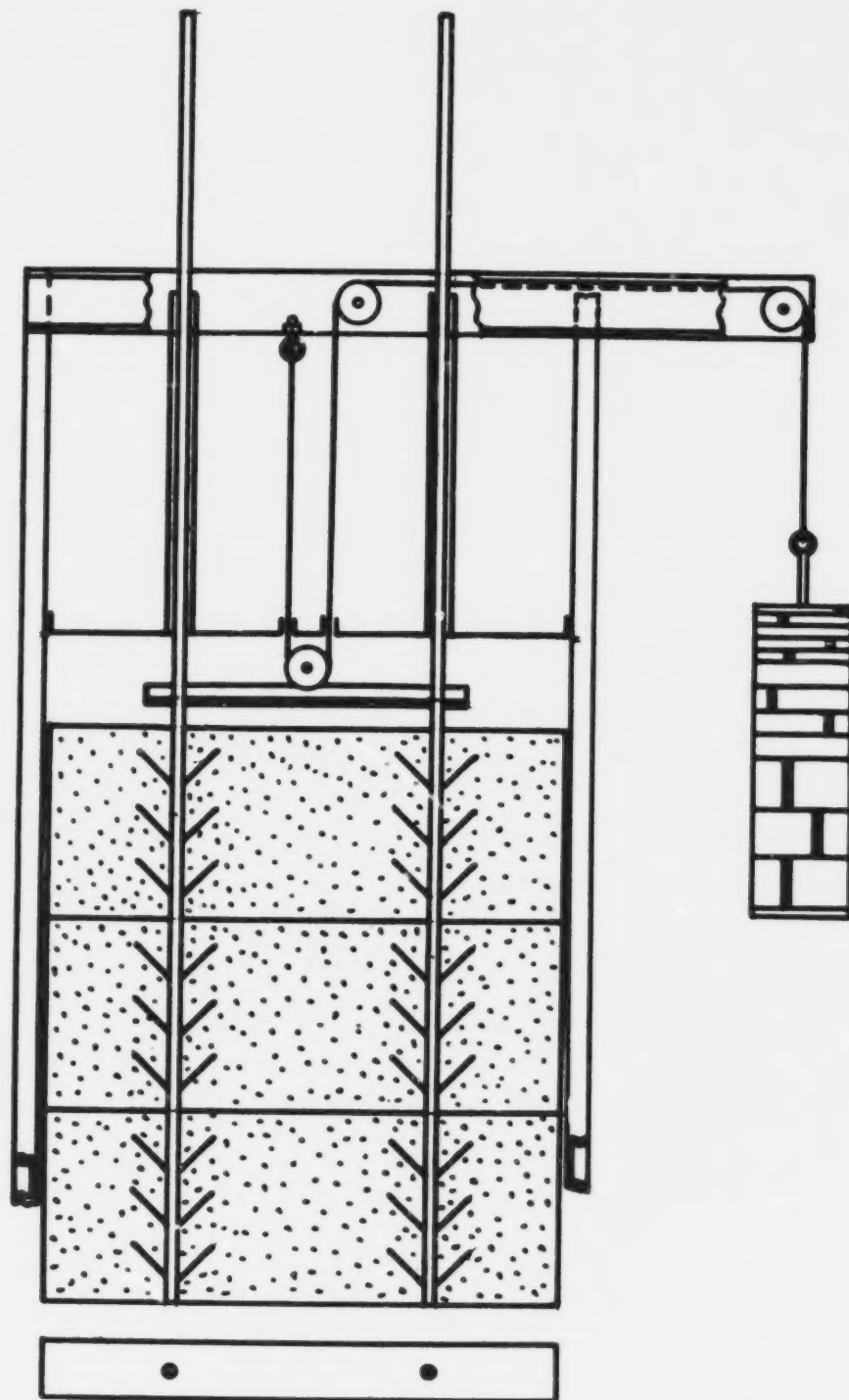


Figure 6. Hanging Damper, Cross Section

Instrumentation and Test Procedure

The refuse was sampled and weighed before charging, usually by classes of materials. Samples were sent to the laboratory for analysis and Btu determination. Table 7 and 8 resulted from one series of samples.

The bulk density of the charge in the furnace was determined by dividing the total weight of charge by the gross volume it occupied in the furnace.

The residue was sorted, screened and weighed. The bulk density of the residue was determined by classifications.

The total forced air was metered through square-edged orifices at the inlets of both fans. The flow through the air valves was metered as was the flow rate of flue gas through the breeching. The pressure drop through the breeching and the gas temperature in the breeching were monitored continually. The barometric pressure and the air humidity were also determined. The breeching served as a flowmeter and had been calibrated by pitot-tube traverse. The flow rate of flue gas at any instant could therefore be calculated.

The combustion gases were sampled continuously from the breeching with one water-cooled probe supplying the continuous gas line for the sampler. The Orsat samples were collected over brine for 15-minute periods early in the run and for 30-minute intervals later. A second sampler was used for a $\text{CO}_2/\text{H}_2\text{O}$ meter. The $\text{CO}_2/\text{H}_2\text{O}$ meter provided the weights of CO_2 and water vapor in the gas on a cumulative basis, with values determined every five minutes⁸.

The temperatures of the breeching flue gas, furnace, refractory floor, and several other regions were measured by Cr-Al thermocouples

and recorded continuously. A bare thermocouple junction was used in the breeching for fast response and to reduce radiation errors. Drafts throughout the system were noted at frequent intervals, but were allowed to vary in response to the draft in the settling chamber of the Jersey City Incinerator.

Smoke was monitored by a photocell opposite a light across the breeching, which was zeroed before lighting the fire and rechecked at the end of the test for any drift.

The dustloading of the breeching gases was monitored by isokinetic sampling of the gases by a water-cooled null-type nozzle of one-inch diameter. While heavier particles had an opportunity to drop behind the bridgewall, most of the finer particles entrained by the gases left through the breeching.

Findings with Test Furnace

After many preliminary observations during daily operation by the Jersey City crew three instrumented tests were undertaken. The first two tests were conducted with mixed refuse piled to an average depth of 8.6 ft and the same weight. The composition and analysis is given in Table 7.

In Test No. 1 the refuse was ignited at the main door and the blowers were turned on; both underfire and overfire added in moderate amount. Ignition proceeded promptly through the charge and temperatures rose rapidly, as shown in Figure 7. As the carbon dioxide content of the flue gas mounted, the excess air decreased and the flames lengthened until the entire furnace and breeching were filled with flame.

The flames intercepted the light beam of the smoke meter and caused signals equal to 90 percent smoke opacity in the breeching at one time. The flames burned out in the plant's settling chamber where excess air was available. No smoke was visible at the top of the chimney.

The blowers were shut off after a half hour, leaving combustion dependent solely on air induced through the clearance at the front doors. The flames shortened promptly and the smoke meter reading fell to zero. The burning continued at high rate for the first hour, after which the temperatures and CO_2 gradually decreased. The charge settled in one hour to about 50 percent of initial volume.

Ninety minutes after light-off the blowers were again turned on. The forced air caused a short period of mild smoking and stimulated combustion, but the excess air also increased, hence the temperatures

TABLE 7
COMPOSITION AND ANALYSIS OF REFUSE CHARGES, TEST NOS. 1 AND 2

<u>Physical Analysis of Charges</u>	<u>Test 1 lb</u>	<u>Test 2 lb</u>
Hardwood lumber	2,700	3,958
Softwood demolition lumber	2,529	1,887
Rotten timbers	1,635	916
Metal chairs with wooden seats and backs	1,950	225
Furniture, wooden	1,392	2,330
Mattresses and beds	272	775
Upholstered chairs and sofas	809	1,125
Tires	605	606
Box of papers	0	70
Total lb	11,892	11,892
Composite Chemical Analysis of Charges:		
Moisture	11.4	Btu/lb 7,740
Carbon	39.8	
Hydrogen	5.1	Theoretical air: 5.05 lb/lb
Oxygen	30.1	refuse
Nitrogen	0.4	
Sulfur	0.2	
Inerts*	13.0	
	100.0 %	

* Includes metal, glass and ash.

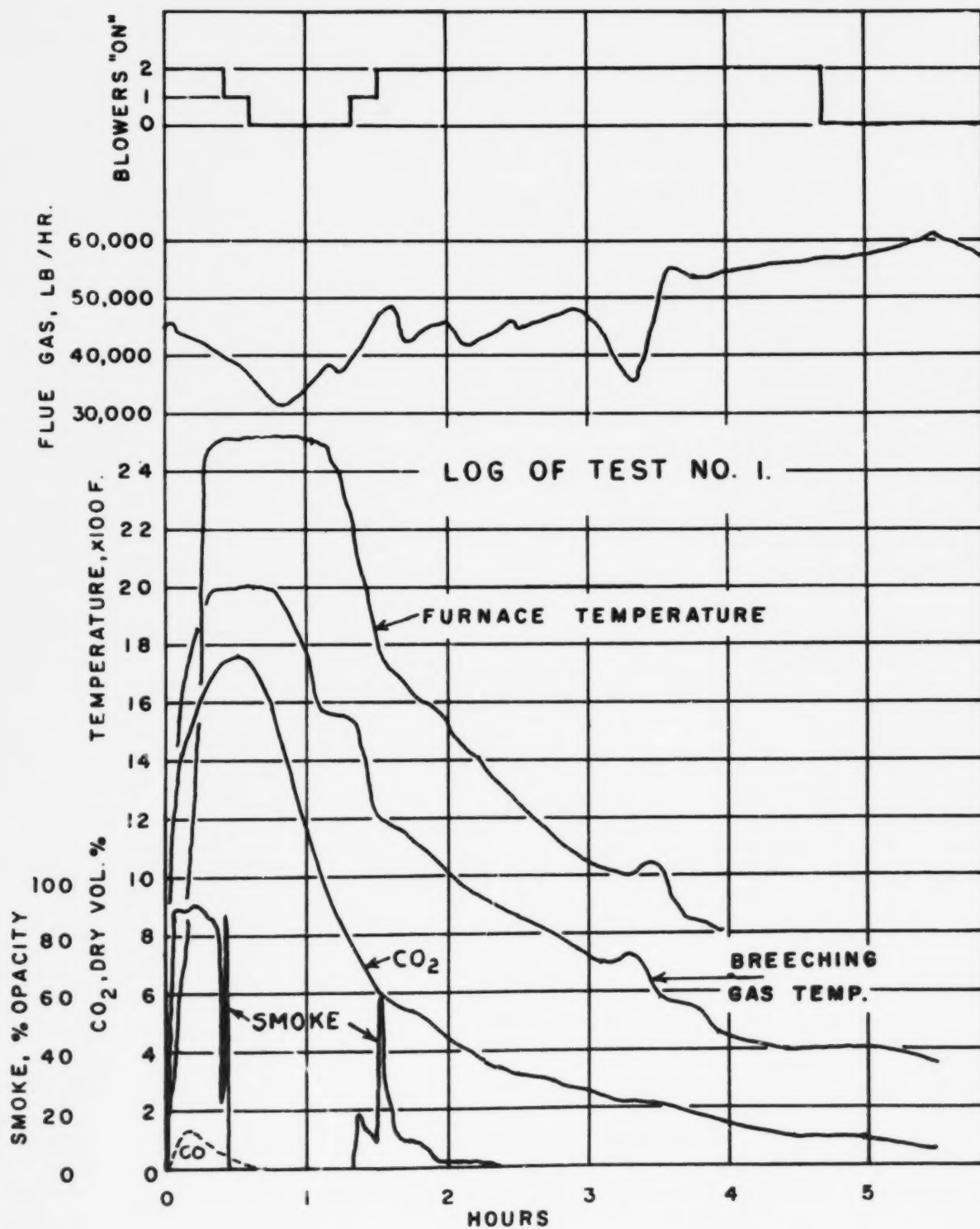


Figure 7. Log of Test 1

continued their slow decline. The test was discontinued after five hours, and the charge was allowed to burn over night by natural draft.

Next morning only 60 lb of charcoal was still glowing. The furnace was cool enough to enter and clean.

Test No. 2 was similar to Test No. 1 except for several procedures. The test log is plotted in Figure 8. The charge was ignited at the top of the bridgwall to reduce the rate of ignition, but the ignition still raced rapidly through the charge. The temperatures and CO₂ content of the flue gas rose rapidly as in Test No. 1. Shutting off the blowers for the remainder of the first half hour did not shorten the flames and a high density "smoke" signal was received. However, on restarting the blowers and continuing on minimal forced underfire air, the smoke decreased to zero.

After 1½ hours total elapsed time, the underfire air was increased slightly, which stimulated combustion, as shown by higher CO₂ and temperatures. After a rather sharp rise, the normal decline of CO₂ and temperatures again set in for the remainder of the run.

Residue from Test Nos. 1 and 2

The residue from each burn was removed and classified, as reported in Table 8.

The original metal gained weight because of the partial oxidation of the iron and the formation of a scale of magnetite (Fe₃O₄). The original iron weight was about 95 percent of the iron residue.

The metallic residue from Test No. 2 was a loose pile of 175 cu ft, and thus had a bulk density of 6.4 lb per cu ft. The bulk was due largely to upholstery springs. As the temper was destroyed in the

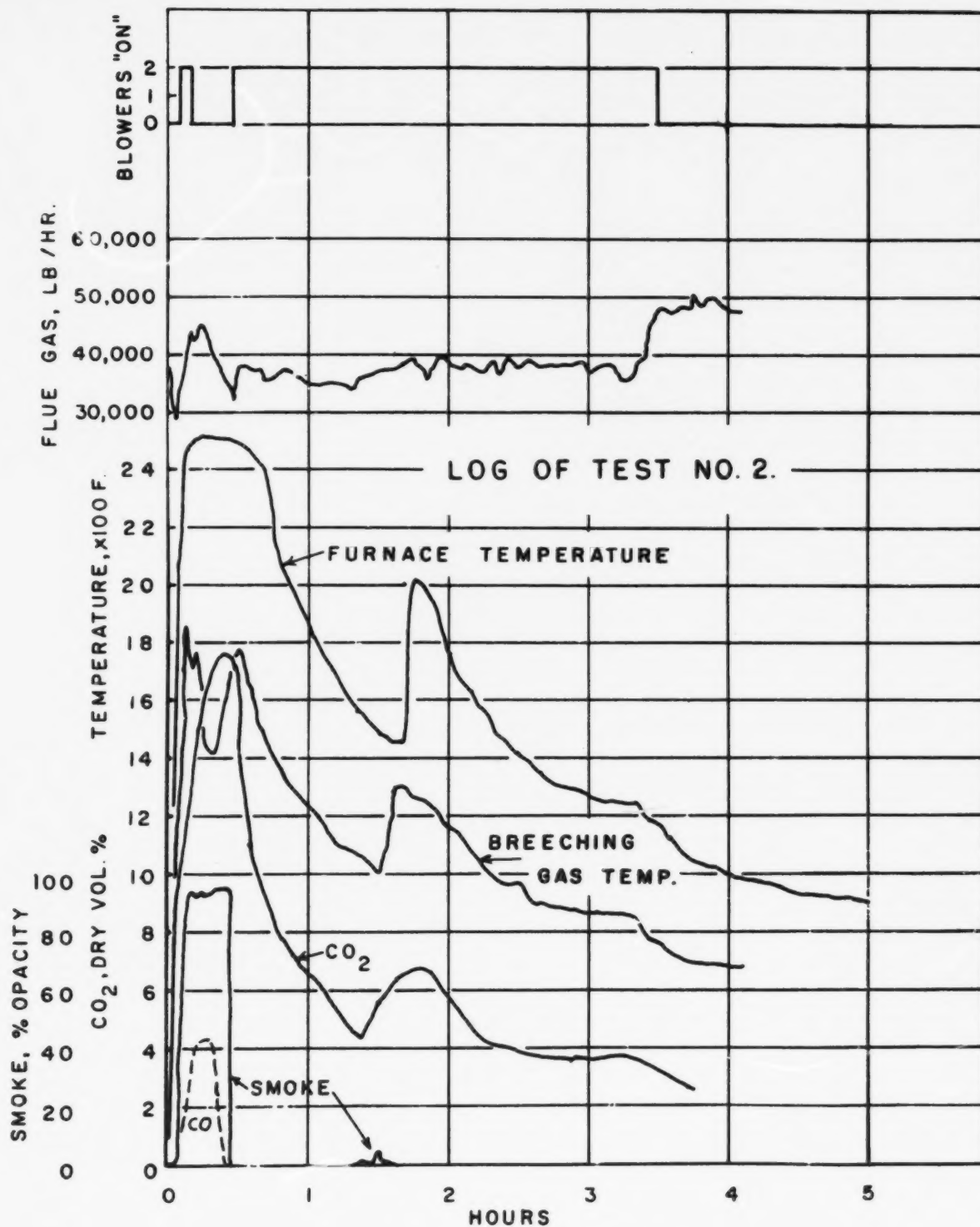


Figure 8. Log of Test 2

TABLE 8
RESIDUE FROM TEST NOS. 1 AND 2

	Test 1 lb	Test 2 lb
Upholstery springs and associated steel	137	458
Auto wheels, rims, tire wire	85	183
Sheet iron	62	43
Chair tubing and misc. steel	1,129	84
Cast iron	0	39
Misc. iron and steel	<u>336</u>	<u>303</u>
Total lb	1,749	1,110
Ash and (-1/4 in.) charcoal	139	130
Glass and clinker	20	9
Charcoal (+1/4 in.)	<u>11</u>	<u>61</u>
Total lb	1,919	1,310
Percent of initial charge	16.1 %	11.0 %

heat, the springs could be deformed like annealed wire. Scavengers were glad to take the steel for sale to scrap balers. The material would compact readily in landfill. The minus 1/4-inch residue, including ash and small metallics, had a dry density of 49 lb per cu ft and was 61.7 percent voids by water test. This residue fraction was 16.7 percent iron and Fe_3O_4 , with the remainder being non-magnetic ash. As the minus 1/4-inch residue contained small screws and nails, this material was sampled and separated magnetically.

The bulk density of the residue from Test No. 1 was higher because more chair iron and less spring metal were present.

Test of Flue Dust Emission

Test No. 3 was conducted in the Jersey City test furnace on the available random assortment of mixed refuse, some of which contained smoke-producing hydrocarbons. The objective was to determine the amount of ash and combustible in the particulate matter from a large charge before secondary combustion or dust removal.

The refuse was all charged into a cold furnace before light-off, and consisted of the constituents listed in Table 9.

The total weight of charge was the same as for Test Nos. 1 and 2.

The charge was hand loaded into the furnace to a height of 7 ft. It was ignited at the door and burned with air induced at the main door by natural chimney draft. The charge ignited rapidly. Flame temperatures behind the bridgwall reached 2,400 F within 35 minutes.

Between the first 15 and 50 minutes after light-off, when rapid devolatilization of the charge occurred, as evidenced by long flames,

TABLE 9
ASSORTED BULKY WASTE CHARGE FOR TEST NO. 3

	<u>lb</u>
Hardwood pallets, unpainted	6,291
Hardwood crates, stenciled	547
House demolition lumber and trim, painted	1,356
Softwood boards and pallets, unpainted	1,571
Green and partly rotted logs	241
Mattresses and carpeting (minor)	586
Auto tires and one wheel	305
Plastic-covered chairs, baby carriage	116
Furniture	665
Paper	<u>205</u>
Total lb	11,892

forced overfire air was added from the arch in the zone of the bridge-wall. Forced underfire and overfire air were also added between hours 3:33 and 4:07 of the burn to accelerate burndown.

The long flames during the first hour largely obscured the light beam of the smoke meter in the breeching; No. 5 "smoke" was measured for 30 minutes. As burning of the flames continued in the settling chamber, there was no visible smoke from the chimney.

Particulate matter in the breeching before burnout in the settling chamber was measured in the breeching during a typical test burn. A special sharp-edged water-cooled isokinetic sampling nozzle was positioned on the centerline of the breeching during the entire burn. The nozzle diameter was one inch. The particulate matter was trapped in wet impingers in ice water.

During the five hours of continuous sampling 59.3 lb of flue gas entered the probe. The dry weight of black particulate collected in the probe, tubing and impingers was 20.8453 gm. The dust loading in the breeching gas was 0.925 lb per 1,000 lb of actual flue gas at 125 percent excess air, or 1.335 lb per 1,000 lb of flue gas corrected to 50 percent excess air.

The collected particulate matter was black. The water-jacketed probe had acquired a sooty greasy black film early in the burn, which was covered by a white deposit acquired later in the run.

Much of the sampler catch was collected during the period of smoke production as the ash content of the particulate matter was only 20 percent.

The dust loading of the gases after passage through secondary combustion chambers would depend on the completeness of burnout

of the carbon and hydrocarbon, thus:

<u>Combustible Content, percent</u>	<u>Ash Content, percent</u>	<u>Net particulate matter, lb/1,000 lb gas at 50 % excess air</u>
80	20	1.335
50	50	0.534
30	70	0.382
10	90	0.297
0	100	0.267

In practice it should be possible to attain a dust loading of 0.3 lb dust per 1,000 lb flue gas corrected to 50 percent excess air, or less if dust collection equipment is added downstream of the secondary combustion chamber.

Mass and Heat Balance -- Jersey City Furnace

To gain further perspective regarding the combustion process of a heavily charged batch furnace, with burnout in the settling chamber, a set of mass and heat balances was calculated for Test No. 3. Table 10 presents the results based on the first five hours of operation.

The net heat release rate was $(2,252,000 - 14,093,000 = 68,159,000$ Btu in five hr. $68,159,000 / (200 \times 5) = 68,159$ Btu/hr per sq ft of hearth. $68,159 / 6,916 = 9.35$ lb/hr per sq ft of hearth, average rate. The maximum rate of burning occurred during the first hour and was probably three times as high as the average. The furnace could have been recharged within two or three hours after light-off.

TABLE 10

MASS AND HEAT BALANCES FOR TEST NO. 3

MASS BALANCE	
<u>Input</u>	<u>lb</u>
Bulky refuse	11,892
Dry air at 2.25 x stoichiometric air	108,144
Air moisture	<u>1,296</u>
Total lb	121,332
<u>Output</u>	
Dry gas	111,286
Moisture	8,055
Fly ash passing through breeching	80
Residue at end of five hour	<u>1,911</u>
Carbon 936, Ash 92, Metals and oxides 883	
Total lb	121,332
HEAT BALANCE	
Base: 75 F, water as liquid	
<u>Input</u>	<u>Btu for burn</u>
HHV of refuse charged 11,892 (6,916)	82,252,000
Heat of vaporization of air moisture	<u>1,370,000</u>
Total	83,622,000
<u>Output</u>	
Sensible heat of dry flue gas at 1,675 F 111,286 (432)	47,073,978
Sensible and latent heat of moisture at 1,675 F, 8,055(1,899 - 43)	14,950,080
Sensible heat in fly ash at 1,675 F 80 (0.25)(1,675 - 75)	32,000
Chemical heat in carbon in residue and fly ash, 1,000 (14,093)	14,093,000
Sensible heat in residue 1,911 (0.20)(1,200 - 75)	429,975
Heat lost to furnace enclosure, etc.	<u>7,042,967</u>
Total	83,622,000

The net heat release rate was $82,252,000 - 14,093,000 = 68,159,000$ Btu in 5 hours.

$68,159,000 / (200 \times 5) = 68,159$ Btu / hr per sq ft of hearth.

$68,159 / 6,916 = 9.35$ lb / hr per sq ft of hearth, average rate.

The maximum rate of burning occurred during the first hour and was probably three times as high as the average. The furnace could have been recharged within two to three hours after light off.

Burning of Green Logs

The cold furnace floor was first covered with a 6-in. layer of demolition lumber (1,000 lb) to serve as kindling. Green logs weighing 25,880 lb were piled on the kindling to a depth of 6.5 ft. The logs had been cut about six months earlier and included sycamore, maple, wild cherry, elm, oak, but no conifers. The logs were sampled by chain sawing off slices, which analyzed 47.5 percent moisture. The moisture content of the bark and outer wood was obviously less than in the center ⁹.

The bulk density of the logs was 19.9 lb per cu ft. The density of the logs was about 50 lb/cu ft. The ash content determined from this burn was 3.5 percent. The calculated analysis follows in Table 11, based on published data ⁸ and moisture determined by sampling the logs.

Figure 9 indicates the progress of the burn. Most of the combustion air was induced through the clearance around the main door. One blower was used during the latter half of the burn to accelerate the burning.

Despite the high CO₂ content of the flue gas, indicative of low excess air, the flue gas was virtually free of smoke at the breeching. The CO₂ declined progressively as the surface area of the logs declined and the voids increased. At any time the outer layer of a log was burning charcoal, under which a layer of wood was drying and devolatilizing. The burning was as rapid as the transport of oxygen to the charcoal surface. The evolution of volatile matter was so gradual that smoke was generally absent.

TABLE 11
ULTIMATE ANALYSIS OF THE LOGS

Moisture	47.5 %	12,293 lb
Carbon	24.7	6,392
Hydrogen	3.0	776
Oxygen	21.2	5,487
Nitrogen and Sulfur	0.1	26
Ash	<u>3.5</u>	<u>906</u>
	100.0 %	25,880 lb

HHV = 4,120 Btu/lb

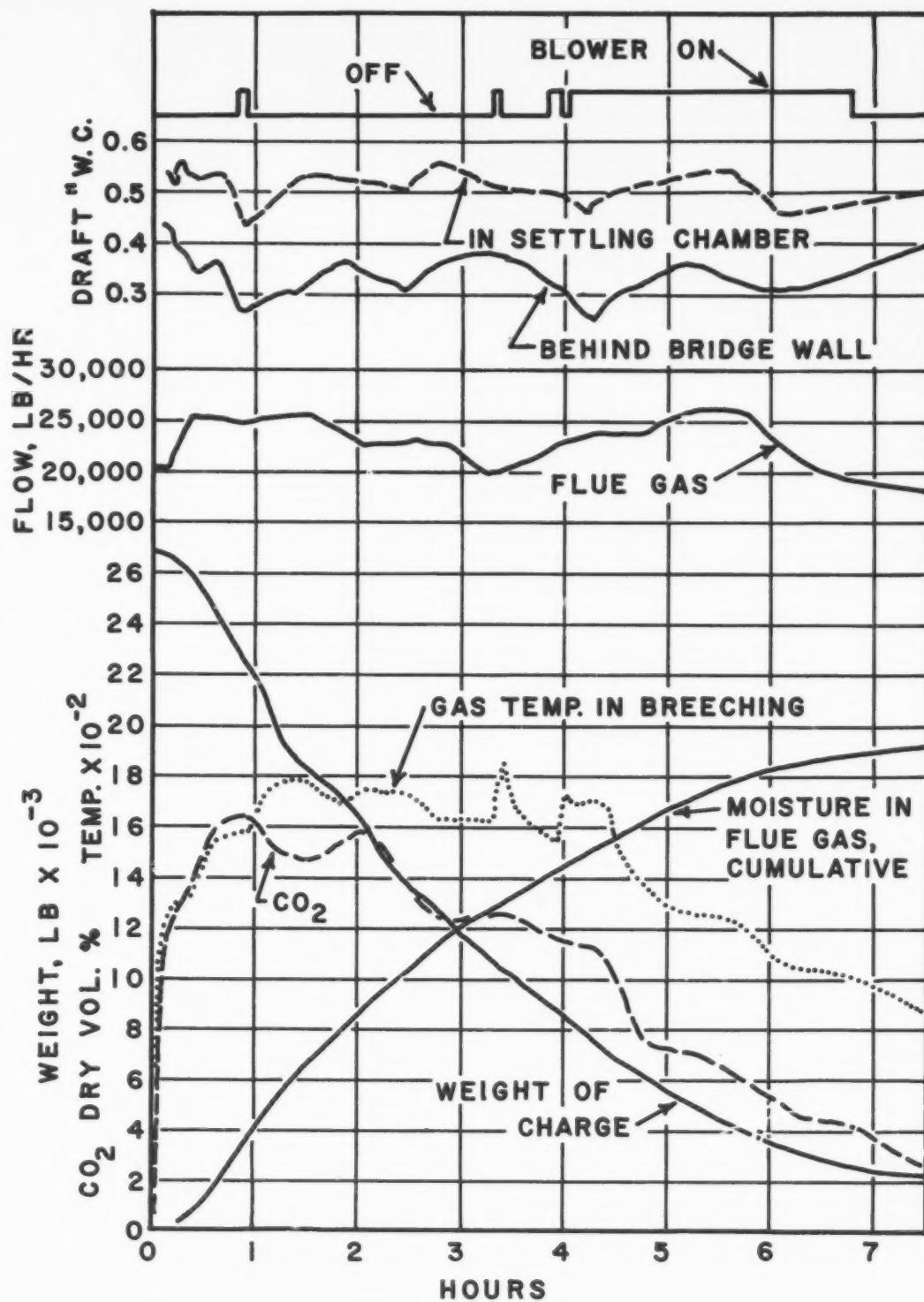


Figure 9. Progress of Burn of Green Logs

The slope of the weight-of-charge curve, Figure 9, was maximum after the first hour following ignition, after which it gradually declined. The dry exterior of the bark helped promote rapid ignition throughout the charge. The rapidity with which the logs burned in the furnace was amazing to the regular operating crew, who had previously experienced logs burning in the open. Heat lost by radiation in open burning was retained inside the furnace, hence there was no smoldering or loss of ignition. The maximum rate of weight loss was 35 lb per sq ft-hr early in the burn. The average rate for the first five hours was 20 lb per sq ft-hr.

The rate of gas flow was largely determined by the available draft downstream of the breeching, which ranged between 0.45 and 0.55 inches water gage. The weight rate of flue gas was determined by using the breeching as an orifice. Numerous calculations were necessary as the gas flow, gas density and gas temperature in the breeching were constantly changing.

Moisture content of the flue gas was determined continuously and cumulatively by means of the gravimetric $\text{CO}_2/\text{H}_2\text{O}$ meter previously described ¹⁰. The flue-gas moisture came from the following sources:

Free moisture in logs	4,900 lb
From combustion of hydrogen	2,880
Air moisture	<u>280</u>
Total	8,060 lb

The slope of the moisture line in Figure 9 denotes that the highest moisture release rates from the charge was at 45 minutes after light-off, with general decline from that time on.

CITY OF DETROIT LOG AND BRUSH BURNER

Design and Test

The City of Detroit, Michigan, erected two nearly identical incinerators to burn the tree trimmings and dead or diseased trees (5, 9). The plan and longitudinal sections are shown in Figure 10.

The logs and branches were delivered to the site by truck and dropped on a concrete apron. The branches (brush) were pushed across the apron and through the brush door into the primary chamber. Logs were deposited in the log chamber by tractor with bucket. Actually, the log and primary chambers were zones of the same furnace.

The units were not designed to burn wastes containing hydrocarbons, such as tires, plastics, asphalt roofing and painted lumber. No secondary combustion space had been provided. The flue gases were quenched with spray water on leaving the furnace in an effort to trap fly ash. Hence, the burning of wastes with hydrocarbon constituents on several occasions had always resulted in smoke emission from the stack.

Forced air was supplied through floor, arch and sidewall ports. Otherwise, the system operated by natural draft. Air leakage around the brush and log doors contributed to the total air entering the furnace.

The incinerators were operated during the day shift and were allowed to burn out unattended over night. Residue was removed in the early morning every second or third day by means of tractor and bucket, after which refiring continued.

The incinerator at the St. Jean yard was operated on a weight test on Monday, October 31, 1966 to determine the actual burning rates at the full rate of operation. The furnace had cooled over

over the weekend. The ashes were removed by front end loader.

A small charge was ignited with oil after which the forced air blowers, which supplied a common air manifold, were turned on. The charging of brush by tractor with pusher blade, and logs by tractor with bucket was continued at intervals from 7:45 A.M. to 2:38 P.M., depending on the rate of burndown of the refuse. A supply of logs was on hand, but brush was received during the day. The weights and tars of all truck loads were recorded. The total refuse consisted of:

Green logs	68,846 lb
Tree branches	<u>15,730</u>
	84,576 lb

The data recorded included the following: weights and time of charging, volumes of representative loads and logs, draft and gas temperature in breeching entering stack, temperature below furnace arch, number of forced air blowers in operation, appearance of stack plume.

Figure 11 is a log of the test. The charging progressed fairly regularly during the day except during the last 30 minutes when the chamber was filled in anticipation of the over-night burndown.

The furnace temperature cycled up and down, as did the breeching gas temperature, because of the batch charging and the opening of the doors. Guided by the furnace pyrometer, the operators turned off one or two blowers when the temperature climbed above 1,800 F. The blowers were also turned off at times when the doors were open for charging. The amount of hot gas with light smoke escaping from the top of the door opening was thus minimized.

All of the brush and a minor fraction of the logs were charged through the front door. Most of the logs were charged through the

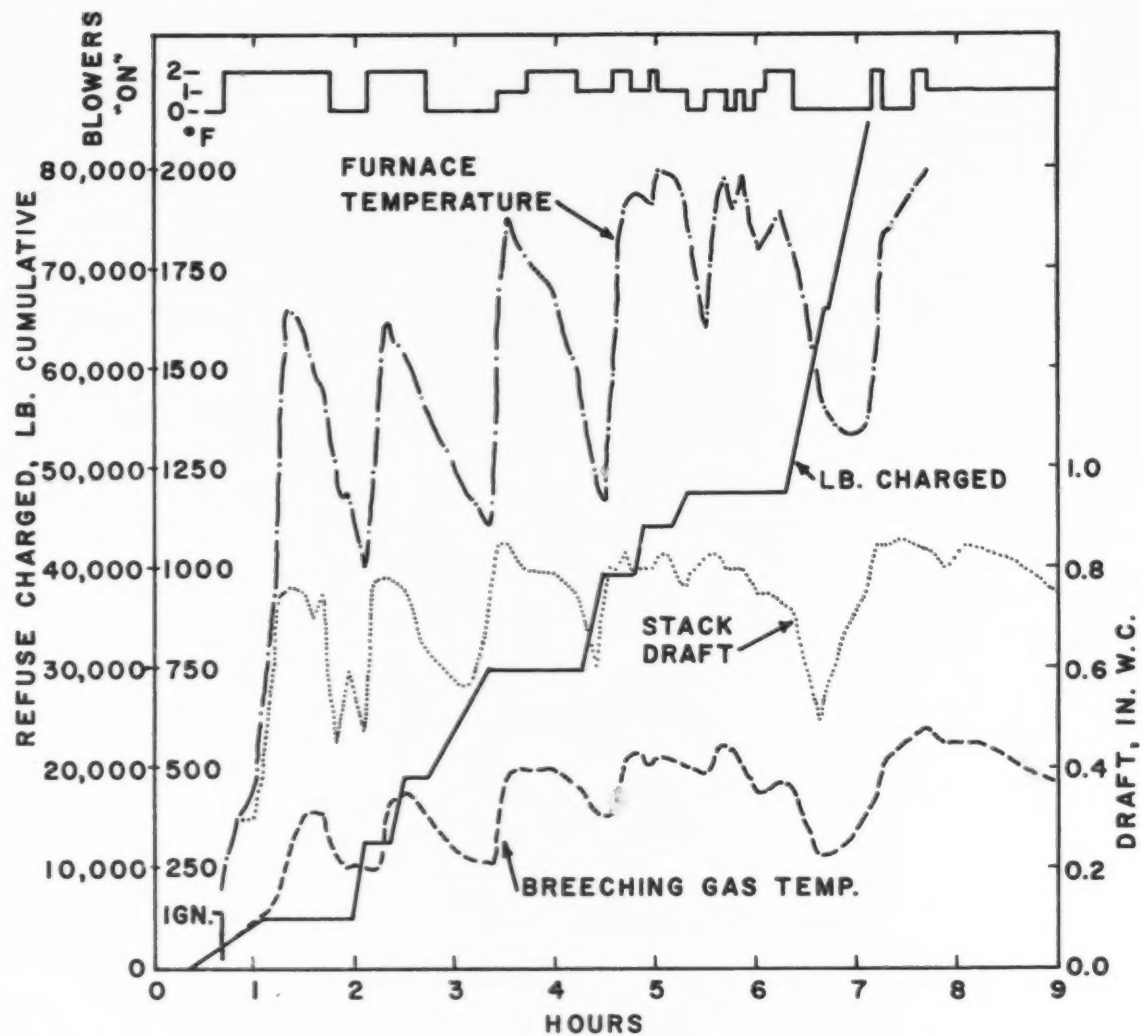


Figure 11. Log of Test of Detroit Brush Burner

side door. The front door was open a total of 1.07 hours and the side door was open 1.12 hours. The doors were left open this long as a convenience for a succession of charges at each opening. The total waste was charged within 6.88 hours of operation.

The stack gases were clear most of the day, with occasional periods of light haze. Light gray smoke was produced during the first 30 minutes until the furnace pyrometer reached 1,000 F.

Test Results

With allowance for the warm-up period and the overcharging at the end of the day, the sustained burning rate at full output was 10,000 lb per hour with this type of refuse. As the hearth area was 550 sq ft, the unit burning rate was $10,000/550 = 18.2$ lb per sq ft-hr.

At 4,125 Btu per lb, the heat release rate was 75,000 Btu per sq ft-hr. As the furnace was 10 ft high, the volumetric burning rate was 7,500 Btu per cu ft-hr.

The elm logs had an average density of 56.6 lb per cu ft. The bulk density of the brush ranged between one and three pounds per cu ft, or 27 to 81 lb per cu yd.

Material and heat balances, Table 12, were derived on the basis of the test data and averaged operating conditions. The gas weights correspond to an Orsat analysis (dry volume) of 9.8 % carbon dioxide, 10.5 % oxygen, and 79.7 % nitrogen. The analysis of the logs and brush is from previous findings. The dust loading of the stack gases is from by the Detroit Bureau of Air Pollution Control. The average temperature of the gases leaving the furnaces was close to 1,550 F, while the gases after the sprays were 425 F. The balances fit all available data. The available chimney draft calculated for the gas volume and temperature equalled the measured draft.

TABLE 12
MASS AND HEAT BALANCE FOR DETROIT FURNACE

<u>Input</u>	<u>MASS BALANCE</u>	<u>Lb/hr</u>
Logs and brush		10,000
Dry air		60,700
Air moisture		280
Spray water, 60 gpm		<u>30,000</u>
	Total input	100,980
<u>Output</u>		
Dry flue gas CO ₂ 9,057, O ₂ 7,018, N ₂ 46,655		62,730
Water vapor		26,035
Water to sewer, 24 gpm		12,025
Fly ash to sewer		25
Fly ash in gases		15
Residue		<u>150</u>
	Total output	100,980
<u>HEAT BALANCE</u>		
Base: 50 F and all water as liquid		
<u>Input</u>		<u>Btu/hr</u>
Higher heating value of logs and brush 4,125x10,000		41,250,000
Heat of vaporization of air moisture 280 x 1065.6		<u>298,368</u>
	Total input	41,548,368
<u>Output</u>		
Heat in dry flue gas at 425 F 62,730 x 90		5,645,700
Heat in water vapor at 425 F 26,035(1,252 - 18)		32,127,190
Heat in sump water and trapped fly ash 12,025(140 - 50) + 25(0.20)(140 - 50)		1,082,700
Chemical heat in unburned carbon at 14,093 Btu/lb		352,325
Heat in fly ash to stack at 425 F		1,125
Sensible heat in residue at 1,200 F		43,125
Heat loss to furnace enclosure, radiation and unaccounted for, 5.5 % adj.		<u>2,296,203</u>
	Total output	41,548,368

General Observations

The floor air ports had proved to be of well-conceived design. They consisted of 1/8-in. annular slots formed inside 3-in. pipes by 2 3/4-in. stainless steel disks 2 inches below floor level. Fine ash was blown out by the air while larger pieces that rested on the disks did not seriously obstruct air flow nor fall into the air supply pipes under the floor. The ports were blown out and checked for blockage after the tractor had loaded out the residue.

The fireclay refractory was worn from abrasion of the brush near the front door. Spalling from temperature cycling was also noted on the arch and walls. No slagging was experienced, and the residue was essentially free of fused ash. The wet refractory baffles and their pipe supports had suffered deterioration. However, the refractory maintenance was reasonable for this class of service.

Minor smoke discharge occurred at the top of the charging door when the door was open. A guillotine door that was opened only as much as needed would restrict the outflow of hot smoke at the top.

The Detroit burners served their purpose well because of good design and a dedicated crew.

BULKY-REFUSE INCINERATOR IN NORWALK, CONN.

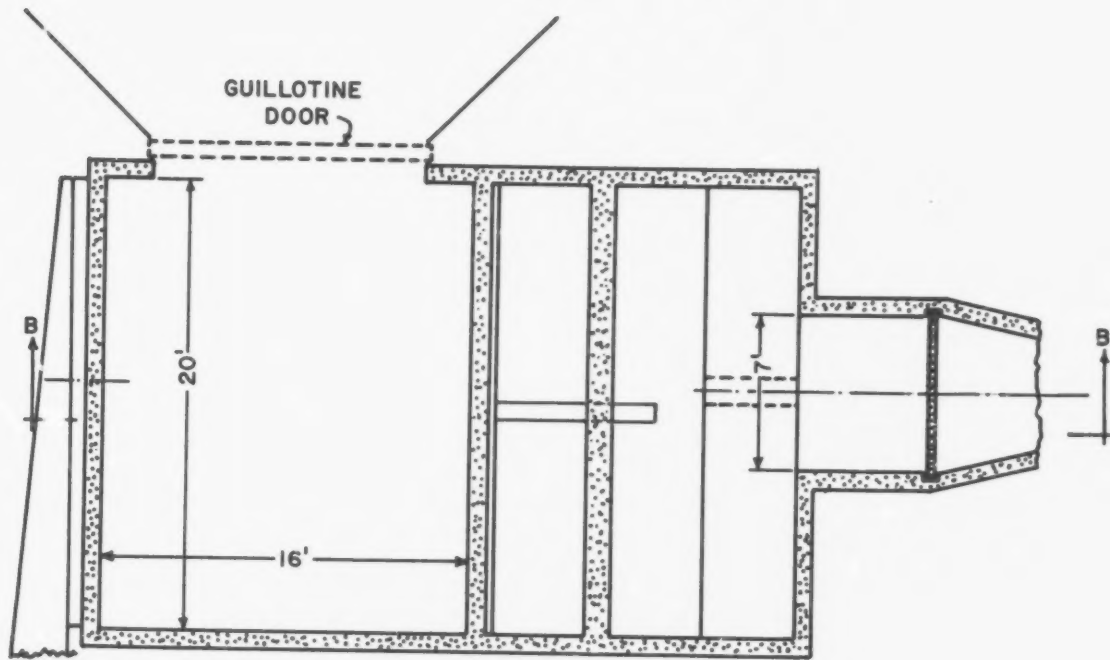
The City of Norwalk installed a bulky-refuse incinerator in 1968 as a supplement to the main incinerator plant. Of refractory construction with steel casing, the design and installation were by Morse Boulger, Inc., to fit an available space and to utilize an existing brick chimney.

Illustrated in Figure 12 , the primary chamber had a plan area 16 x 20 ft, or 320 sq ft, and a volume of 6,048 cu ft. The refuse was charged by a tractor with a 1-yd bucket operating through the 12 x 12 ft door opening. The floor was a refractory hearth without ports for admission of combustion air. Two rows of horizontal air nozzles, 70 in number, along the side wall were supplied by a blower under control of the operator.

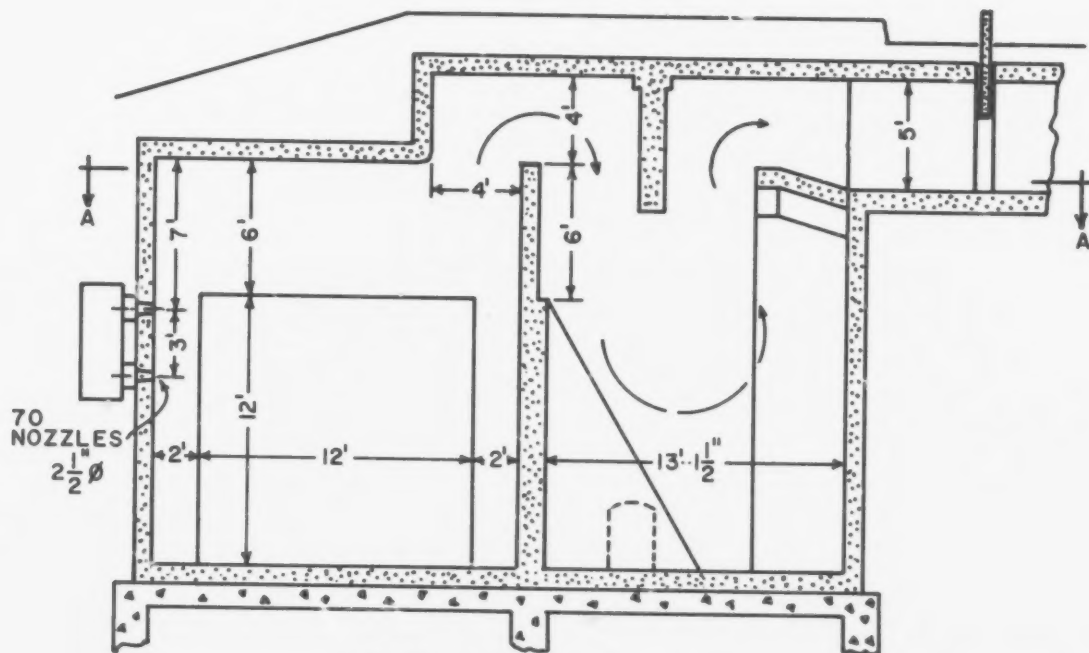
Combustion gases passed over a buttressed bridgwall, into a secondary combustion chamber of 6,115 cu ft where burnout occurred and heavy fly ash was dropped out. Mixing to assist burnout of flames and any smoke from the primary chamber took place in the several turns of the gases between the two chambers and under the patented arch near the exit of the secondary chamber.

Furnace draft could be controlled by a hanging damper at the exit of the secondary chamber. The refractory-lined flue from the damper to the 125-ft chimney was 34 ft long. However, on the days of testing, October 30 and 31, 1969, the full chimney draft was not available because the damper at the base of the stack connecting to other idle furnaces could not be closed completely.

Refuse not acceptable to the regular City incinerator was diverted after weighing to the bulky-waste unit and dumped on the concrete apron in front of the guillotine door. The weights of the components



PLAN SECTION A-A



ELEV. SECTION B-B

FIGURE 12. NORWALK BULKY-WASTE INCINERATOR

of each load were estimated during the tests. As given in Table 13 , the loads contained mainly tree trimmings, ripe leaves, demolition lumber, and general household trash. Metallic items of sufficient size were salvaged by hand loading on a scrap-yard truck. Their weights were not included in the table.

The average analyses, Table 14 , were estimated by referring to earlier data ^{8, 11} and by calculating the composite analyses. Higher heating values were computed by assuming 8,900 Btu per pound of dry organic matter.

Figure 13 is a log of the weights charged into the primary chamber by the tractor. The fires were ignited prior to 9 A.M. and additional charges were added at the operator's option after the previous charges had passed their most active period of flaming.

Loads were pushed across the apron, and up on the pile; some material spilled to the sides and rear while much remained at the top of a somewhat conical pile to a maximum height of $8\frac{1}{2}$ ft. The door was closed to within 8 to 10 inches of the floor after a charge or a series of charges.

About one-half of the combustion air entered the primary chamber under and around the main door by natural draft. It flowed up the pile, where it caused the most active burning on the front face of the pile. The overfire air blower delivered 8,400 cfm or 38,000 pounds of air per hr horizontally over the top of the pile, at a nozzle velocity of 3,500 ft per minute. The air jets contributed oxygen to the flames and provided turbulence and mixing as the jets entrained furnace gases. The blower was shut off when the charging door was open.

Figure 13 also illustrates the fluctuations in gas temperature midway along the exhaust flue, as measured by chromel-plumel thermocouple and recorder. The fluctuations reflect the irregular burning

TABLE 13

REFUSE CHARGED INTO BULKY-REFUSE INCINERATOR
(Norwalk)

	Test No. 1 Oct. 30	Test No. 2 Oct. 31	Average, %
	lb	lb	
Green wood and brush	3,330	5,000	9.5
Semi-dry wood	30,210	14,280	51.0
Leaves	14,704	8,500	26.6
Textiles	1,060	980	2.3
Paper	1,300	3,450	5.4
Asphalt, plastics	400	800	1.4
Metal	500	470	1.1
Glass, ceramics, ashes	240	2,160	2.7
Totals, lb	51,744	35,640	100.0 %

TABLE 14

ESTIMATED REFUSE COMPOSITE ANALYSES, WEIGHT PERCENT
(Norwalk)

	<u>Test No. 1</u>	<u>Test No. 2</u>
Moisture	19.9	21.0
Carbon	33.1	31.3
Hydrogen	4.5	4.2
Oxygen	28.4	28.8
Nitrogen	0.7	0.5
Sulfur	0.1	0.2
Metal		
Glass, ceramics	13.3	14.0
Ash		
	<u>100.0</u>	<u>100.0</u>
Btu per pound	5,945	5,785

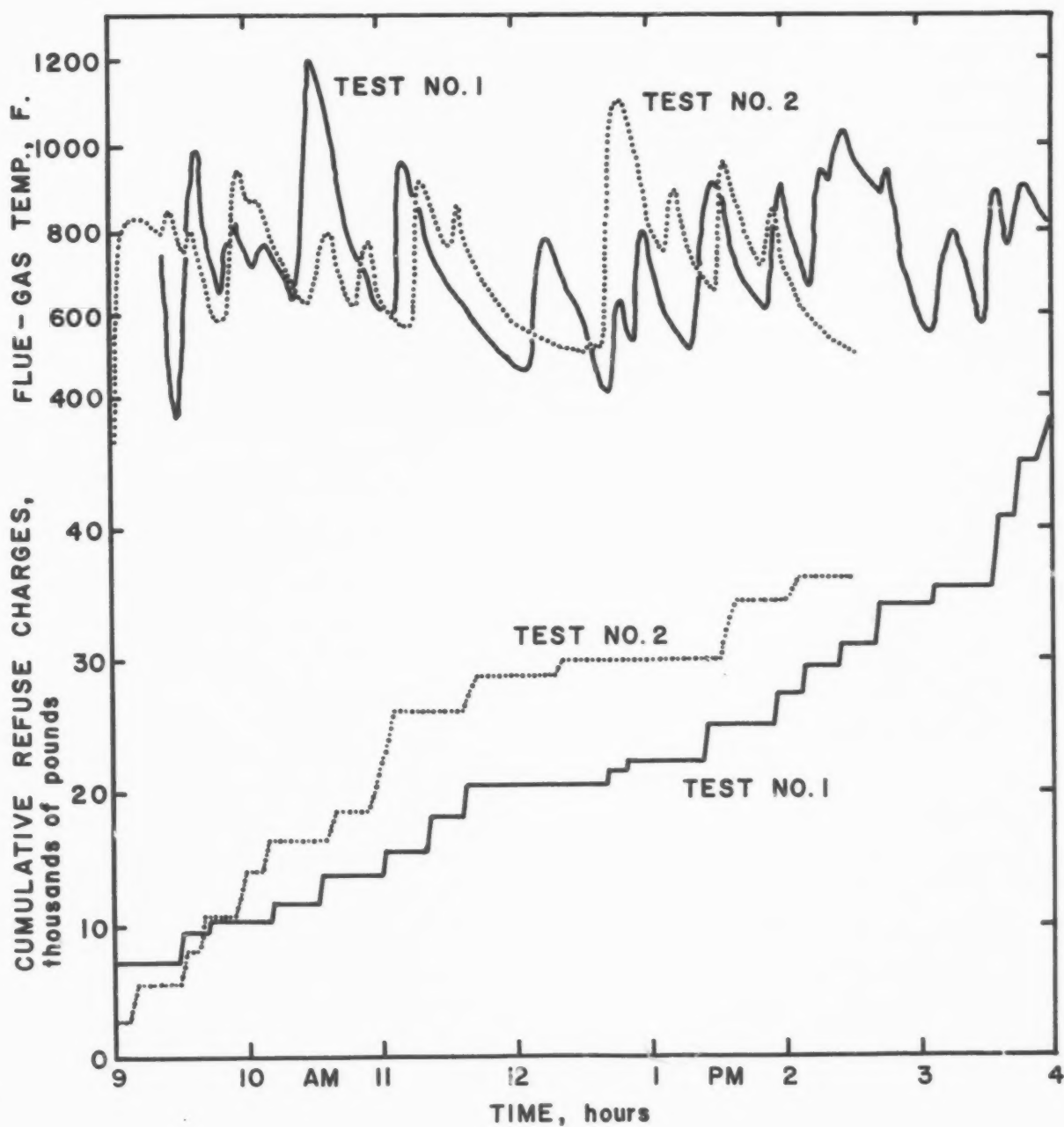


FIGURE 13. LOG OF TESTS AT NORWALK, CONN.

rates, which increased rapidly following charges of dry lumber and declined during lulls in charging. The average flue gas temperature was 698 F during Test 1 and 716 F during Test 2.

Flue gas was sampled continuously with a water-jacketed probe near the center and mid-length of the flue. Hourly samples were collected over brine and analyzed by Orsat apparatus. Table 15 presents the flue gas analyses on the dry basis, and shows the average carbon dioxide content to be only 3.5 and 3.2 percent respectively, for Test No. 1 and Test No. 2. The corresponding excess air percentages were 444 and 451, respectively, based on the combustion that actually occurred.

Smoke from the chimney was nearly clear (faint white haze against blue sky) during both tests except for a few minutes of No. 1 Ringelmann. Rubber tires produced smoke except when carefully placed one at a time immediately inside the charging door, where they would burn slowly.

By 4 P.M. on the first day the burning pile in the primary chamber was 7 ft high at the center and covered the entire floor. The pile was calculated to contain 1,600 cu ft and to weigh about 19,200 pounds, based on an estimated density of 12 pounds per cu ft. Except for possibly 100 pounds of fly ash deposited on the floor of the secondary chamber and lost with the flue gas, all of the inorganic matter in the charges was in the pile, together with charcoal and other unburned refuse. Five thousand pounds of leaves were charged after 4 P.M.

The pile was left to burn over night by natural draft, with air admitted under the guillotine door. The refuse had burned back 5 feet at the floor but was still 8 ft 6 inches high when the furnace was opened at 5:00 A.M., October 31.

Removal of residue from Test No. 1 began at 5:30 A.M. on October 31 and continued until 7:22 A.M. When the pile was opened by tractor

TABLE 15

FLUE GAS ANALYSES, DRY VOLUME PERCENT (ORSAT)

<u>Time of Sample</u>	<u>Test No. 1</u>			
	<u>CO₂</u>	<u>CO</u>	<u>O₂</u>	<u>N₂</u>
10:45 - 11:45 A.M.	2.3	0.0	18.6	79.1
11:45 - 12:45 P.M.	2.3	0.0	18.6	79.1
12:45 - 1:45	4.0	0.0	16.6	79.4
1:45 - 2:45	6.0	0.0	14.0	80.0
2:45 - 3:45	2.8	0.0	17.8	79.4
Average	3.5	0.0	17.1	79.4
<u>Time of Sample</u>	<u>Test No. 2</u>			
	<u>CO₂</u>	<u>CO</u>	<u>O₂</u>	<u>N₂</u>
9:05 - 10:00 A.M.	3.6	0.0	16.6	79.8
10:00 - 11:00	3.2	0.0	17.2	79.6
11:00 - 12:00	2.2	0.0	18.2	79.6
12:00 - 1:00 P.M.	4.0	0.0	16.1	79.9
1:00 - 2:00	3.8	0.0	16.7	79.5
2:00 - 2:30	1.5	0.0	19.3	79.2
Average	3.2	0.0	17.2	79.6

bucket, it resumed flaming. As successive tractor bucket loads, 31 in total, were removed, the pile flamed vigorously, showing that much charcoal and volatile matter were present. The hot residue was loaded into a truck and quenched by fire hose during the entire operation. Five truck loads were removed, weighed, and deposited in a landfill. The net weight of wetted residue from Test No. 1 was 25,460 pounds, with an average density on the truck of 654 pounds per cubic yard.

To evaluate the combustion performance, mass and heat balances were prepared for the operating period between 10:45 A.M. and 3:45 P.M. of Test No. 1. See Appendix A. These balances show the following on an hourly basis:

Refuse charged per hour	6,920 lb
Refuse charged less moisture less inerts	
6,920 - 1,378 - 921	4,621
Combustible in residue	
2,743 - 82 - 958 - 10	<u>1,693</u>
Combustible burned	2,928 lb
Combustible burned/Combustible charged	63.4 %
Heating value of refuse charged	41,605,800 Btu
Heating value of residue combustible	<u>22,620,600</u>
Heating values of refuse released	18,985,200
Heat released/Heat charged	45.5 %

Discussion of Results

The Norwalk B-R incinerator was charged with refuse during the day shift but burned 22 hours a day. Fly ash emission was kept low by burning a pile only with overfire air, only part of which entered the outer zone of the pile. Because air did not penetrate into the core of the pile, the residue contained considerable unburned fuel.

The net burning rate during the active day shift was only $2,928/320 = 9.15$ pounds of combustible matter per hour. The net heat release rate during the day shift was only $18,985,200/12,163 = 1,560$ Btu per cu ft-hr.

No doubt, the layer of leaves on top of the fire at the end of the charging day caused a lessening of the overnight burning rate. By charging at a lower rate during the daytime, the percentage of the fuel burned would have increased.

When the Norwalk unit is equipped with a gas scrubber, underfire air ports in the floor should also be added to increase the burning rate and to reduce the combustible in the residue.

BURNING OF BULKY REFUSE ON A ROCKING-GRATE STOKER

The burning of demolition lumber and other bulky waste in mechanical-grate incinerators of municipal size and type has been attempted in the past. Economic advantages for a dual-purpose furnace, one that can burn bulky waste or regular municipal collections from garbage cans, have been handicapped by technical problems.

On March 2, 1970, a test was conducted in Furnace No. 3 of the Oceanside Refuse Disposal Plant, Oceanside, Long Island, N.Y.¹² The furnace was rated at 150 tons a day with normal refuse. The charging chute delivered a continuous layer of refuse 4 ft 9 in. deep to a three-section Flynn and Emrich rocking-grate stoker, which was 10 ft wide x 26 ft 8½ in. long. The active projected grate area which received forced underfire air was 182.3 sq ft. This type of stoker provides vigorous agitation to the fuel bed in contrast to a travelling-grate stoker.

Seven truckloads of bulky waste totalling 15,770 pounds were assembled. All material was cut to lengths under 5 ft to pass through the 9' - 4" x 4' - 0" charging gate opening. Included were 4 auto tires, furniture, mattresses, carpetting, hardwood pallets, 2" and 4" planks, 1" and 4" x 4" lumber, snow fence slats, an aluminum folding table, seat springs, automobile exhaust pipes, brush, green branches up to 6" dia., empty 5-gallon oil cans, cardboard boxes, garden hose and sponge rubber. The bulk density of the loads was 6.05 lb/cu ft. Except for the brush and green branches (~ 50 % moisture), the other wood contained not over 15 % moisture.

Selected heavy pieces of wood were tagged with steel bicycle wheels and hub caps which were nailed on, hopefully to aid in

identifying the pieces of wood and to time their burning period.

The furnace had been burning normal refuse steadily prior to the start of the test, with the furnace thermocouple indicating 1,400 to 1,550 F, and the grates stroking on a 3.5-minute cycle. The charging of normal refuse was halted and bulky waste was charged exclusively. When the normal refuse was fed out of the chute and bulky waste entered the burning zone, the furnace temperature began to climb. Within 24 minutes the furnace temperature reached 1,950 F. It was necessary to cut the stoker stroking rate to 6 minutes per cycle to reduce the charging rate to 6,300 lb per hr and to prevent exceeding 1,950 F furnace temperature. The rated charging rate of normal refuse was 12,500 lb per hr.

The lumber and timber produced a very hot bed of charcoal on the middle stoker section, which melted the aluminum and iron. The molten metal ran through the grate into the sluice water troughs. The metal markers on selected timbers were not seen in the fire. Even the heaviest green branches were consumed by mid-length of the furnace. During the period of highest furnace temperatures, long flames entered the spray chamber following the furnace, where they were quenched. Ringelmann No. 1 and No. 2 smoke was observed, which was higher than with normal refuse.

After 15,670 pounds of bulky waste had been charged, charging of normal refuse was resumed. While the bulky waste burned out and the normal refuse fuel bed became re-established, the furnace temperature returned to normal. When the fuel bed again lengthened and residue from the post-test refuse reached the discharge end of the grate, no evidence of the metal items in the bulky waste was found.

The burning rate of the bulky refuse, after reducing the frequency of grate motion, was 65 pounds an hour per sq ft of grate

area, heat release of almost 500,000 Btu per sq ft-hr. The area heat release rate was almost twice that for normal refuse.

In summary, the findings were:

1. Bulky refuse consisting largely of demolition lumber has a high porosity to air, ignites and burns rapidly. The low ash content of wood offers little restraint to the rate of oxidation.
2. Fire converts a deep bed of lumber to charcoal, which breaks down by grate agitation to a porous layer of charcoal. Underfire air generates temperatures in the charcoal that readily melt steel objects in the refuse, causing molten iron to flow to and through the grates.
3. The continuous burning of deep beds of bulky waste of low ash content on a rocking-grate stoker is not advisable, because of probable damage to the grates and sidewalls by excessive temperatures and molten iron from the refuse.

MULTI-PURPOSE INCINERATOR, STAMFORD, CONN.

The culmination of the experience to date with bulky-waste incinerators is exemplified in a large plant that has been operating for over two years in the City of Stamford, Conn. Conceived by Norman W. Wagner, former Supt. of Sanitation, and detailed by James P. Purcell Associates, the unit has three primary furnaces and one secondary chamber. Forced air is supplied through ports in the floors and in the sidewalls. The product gases are spray cooled to 600 F and cleaned by an electrostatic precipitator. An induced draft fan and a tall steel stack supply the draft.

The furnaces are charged by tractor with a pusher blade. The daily charges average 100 tons, and include bulky waste as well as large quantities of corrugated boxboard and rubbish. Equipment is also available to burn hydrocarbon liquids in the secondary chamber.

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